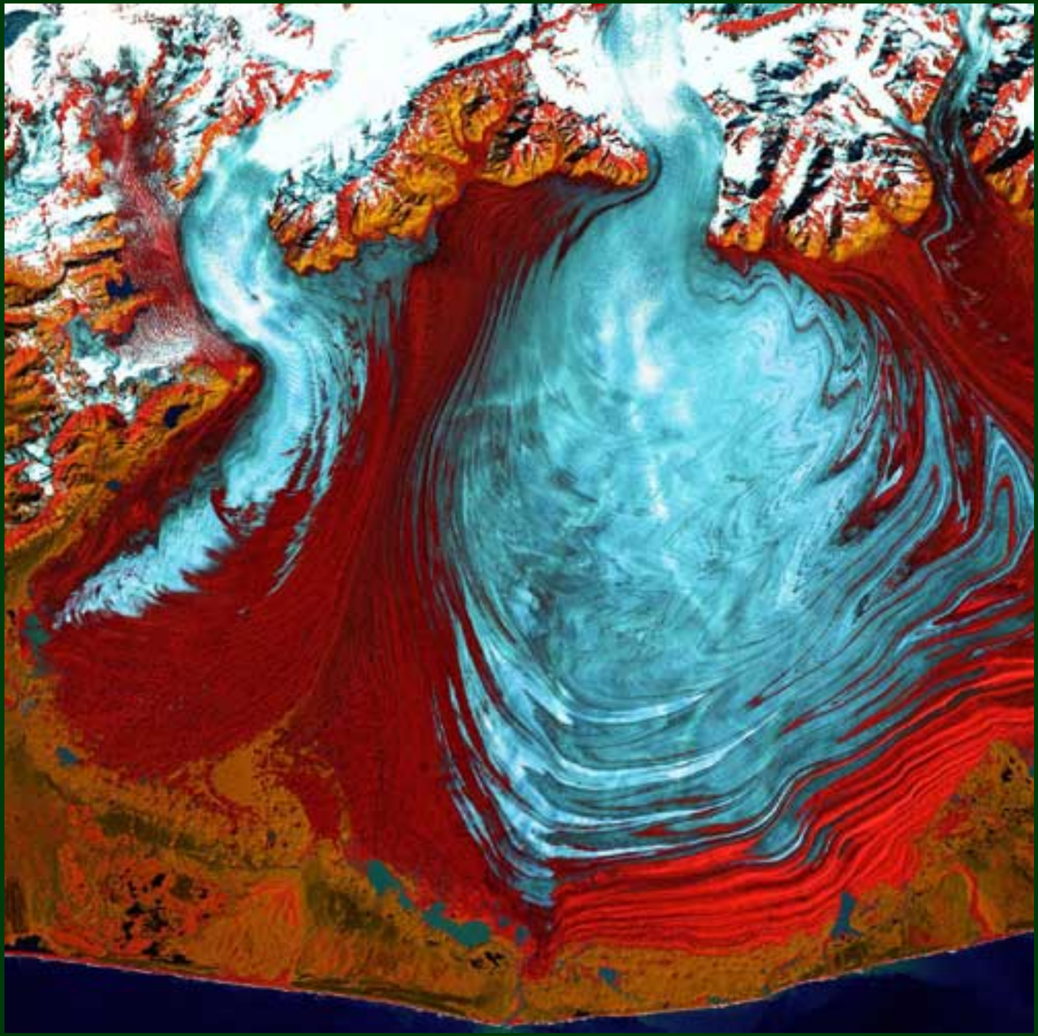
More than a Pretty Picture:
How Landsat Images Are Made



Malaspina Glacier,
Alaska

Colors in satellite images represent data about the Earth.

To understand what the colors mean, we need to understand light.

Landsat image of Betsiboka River, north-central Madagascar.

Light is energy that radiates from its source.

Photo: Jeannette Allen

All objects with a temperature above absolute zero (-273 degrees Celsius) reflect and emit energy that radiates through space.

Photo: Jeannette Allen

This radiant energy has electrical and magnetic effects, and so it can be called, “electromagnetic radiation.”

Photo: Jeannette Allen

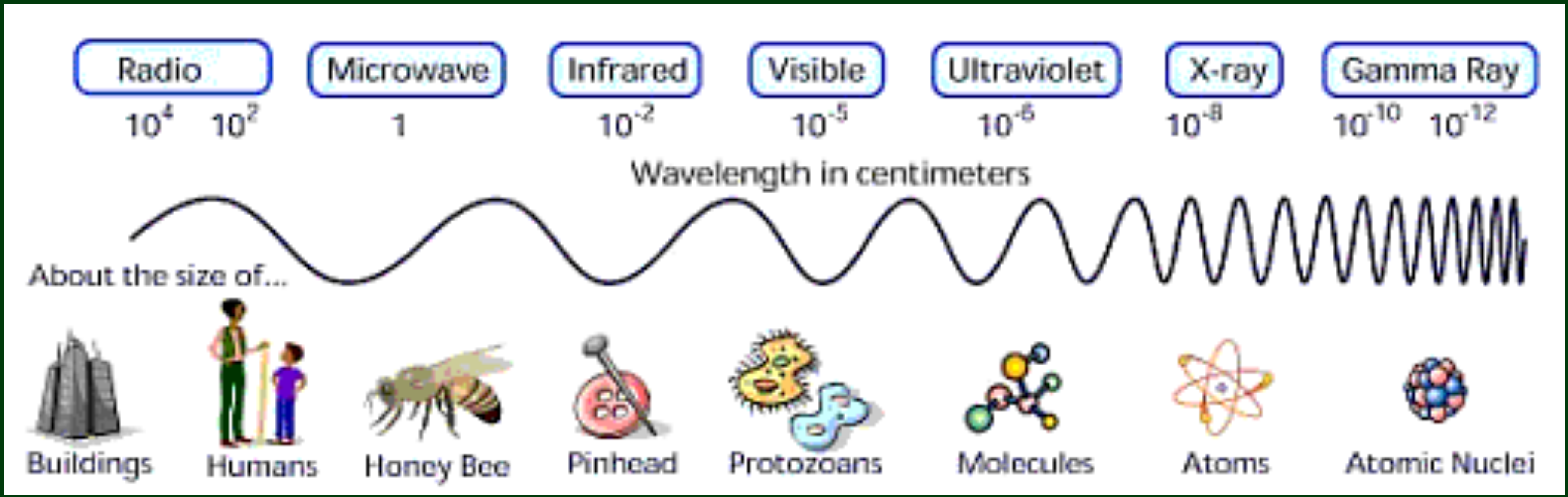
Electromagnetic radiation is the means for many of our interactions with the world.

You can see around you because of light energy. When you tune your radio, watch TV, send a text message, or pop popcorn in a microwave oven, you are using electromagnetic energy.

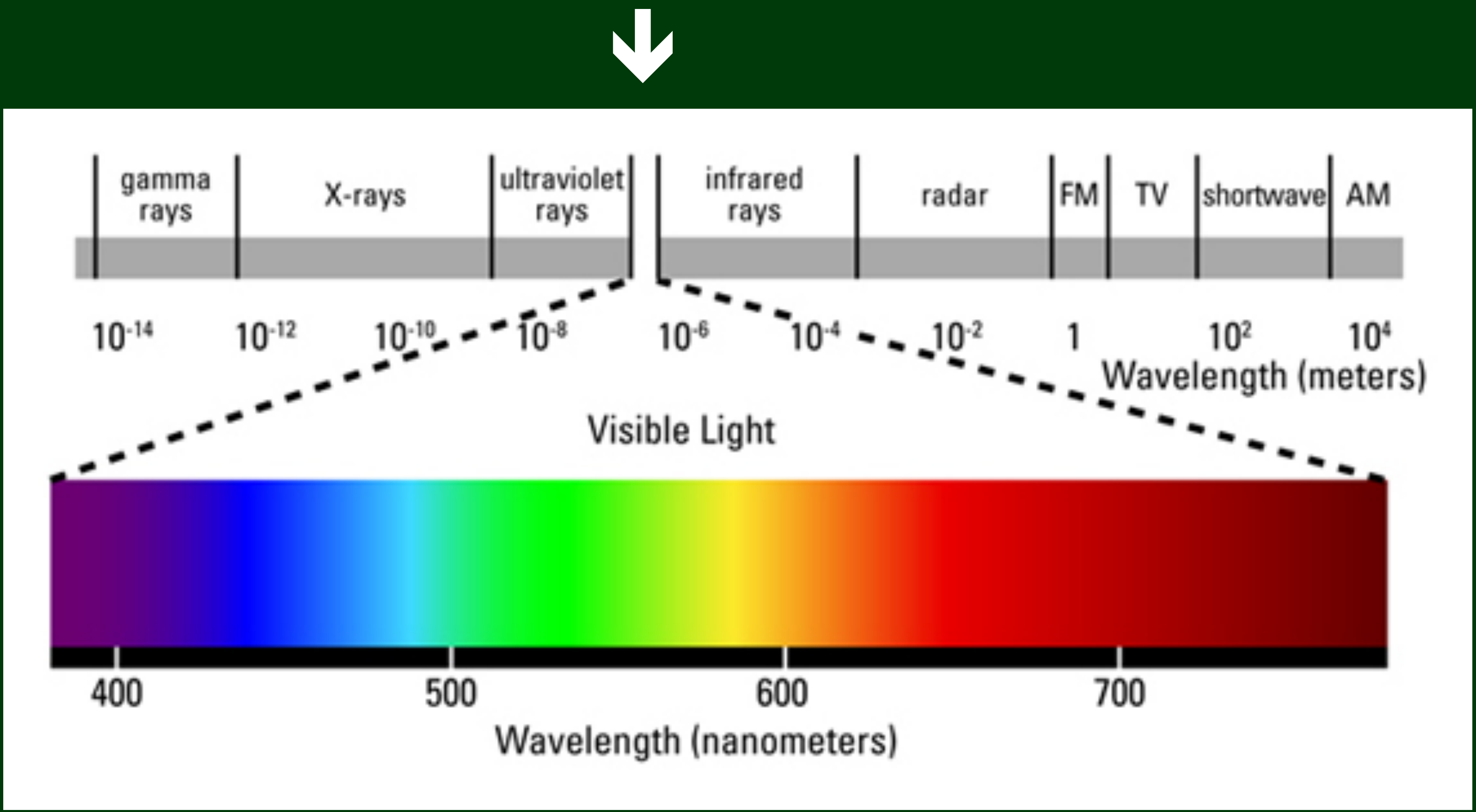
Photo: Jeannette Allen

The *whole* electromagnetic (EM) spectrum consists of the longest wavelengths (radio), shortest ones (gamma rays), and everything in between.

People have grouped EM waves into these categories in order to talk about them.



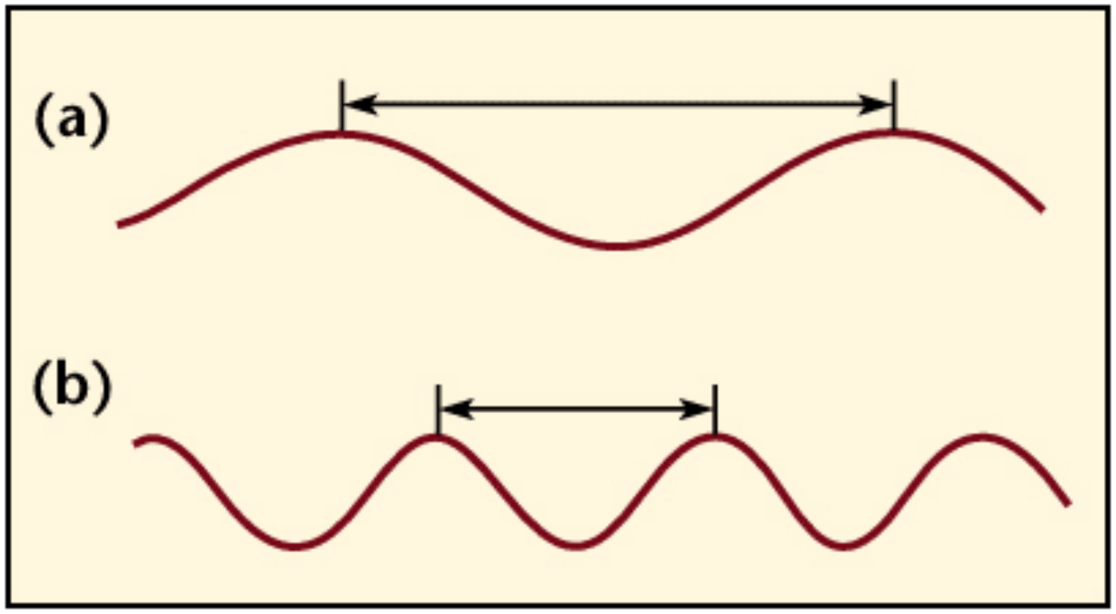
Visible light, the light we see with our eyes alone, is a *very small part* of the whole spectrum of radiant energy in the universe.



We measure radiant energy in wavelengths, from crest to crest.

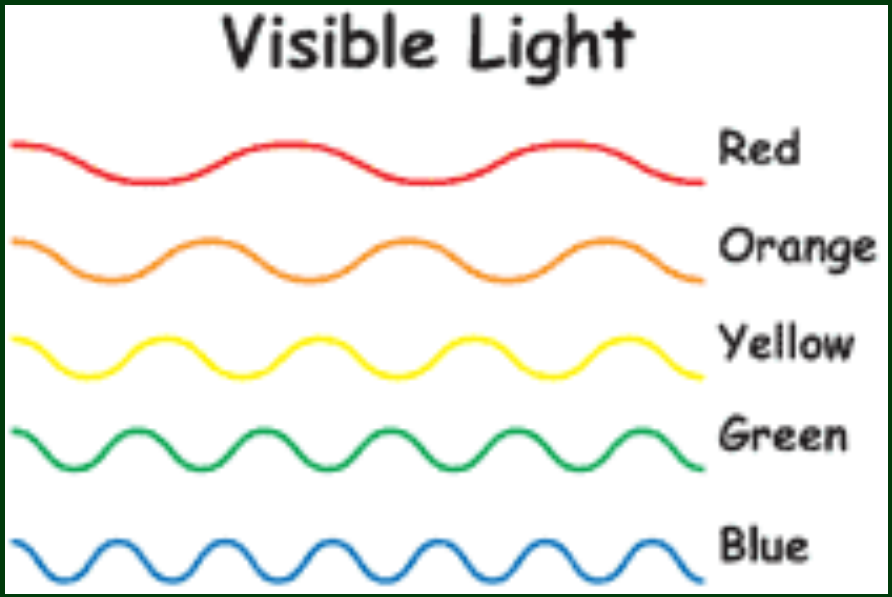
Wavelength (a) ➔
is longer

than wavelength (b)
➔



Colors have different wavelengths!

We see colors as different *because* they have different wavelengths.

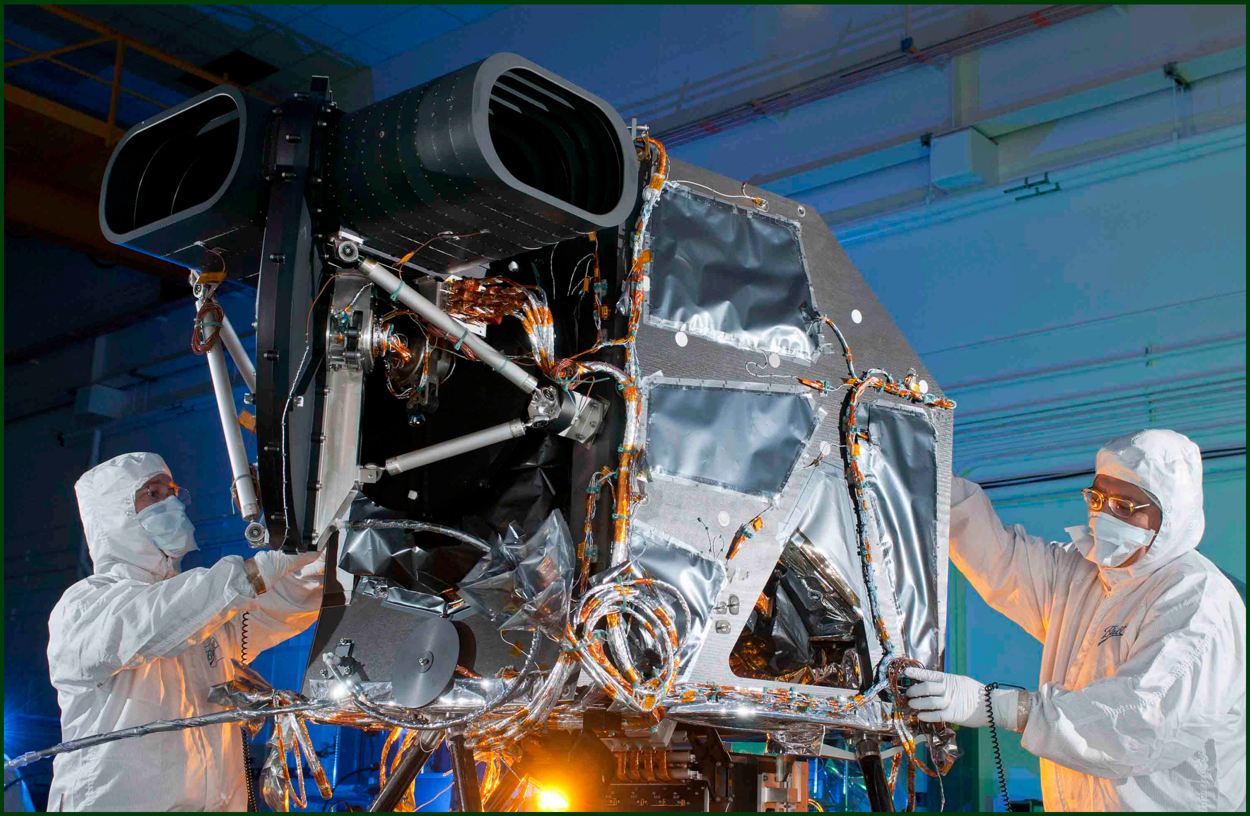


<u>Red</u> has the *longest* wavelengths of visible light, and <u>blue/purple</u> has the *shortest* wavelengths of visible light.

Our eyes detect the entire visible range of those wavelengths, and our brains process the information into separate colors.

Photo: Jeannette Allen

Landsat instruments are designed to detect visible and infrared wavelengths.



The Operational Land Imager (OLI) under construction

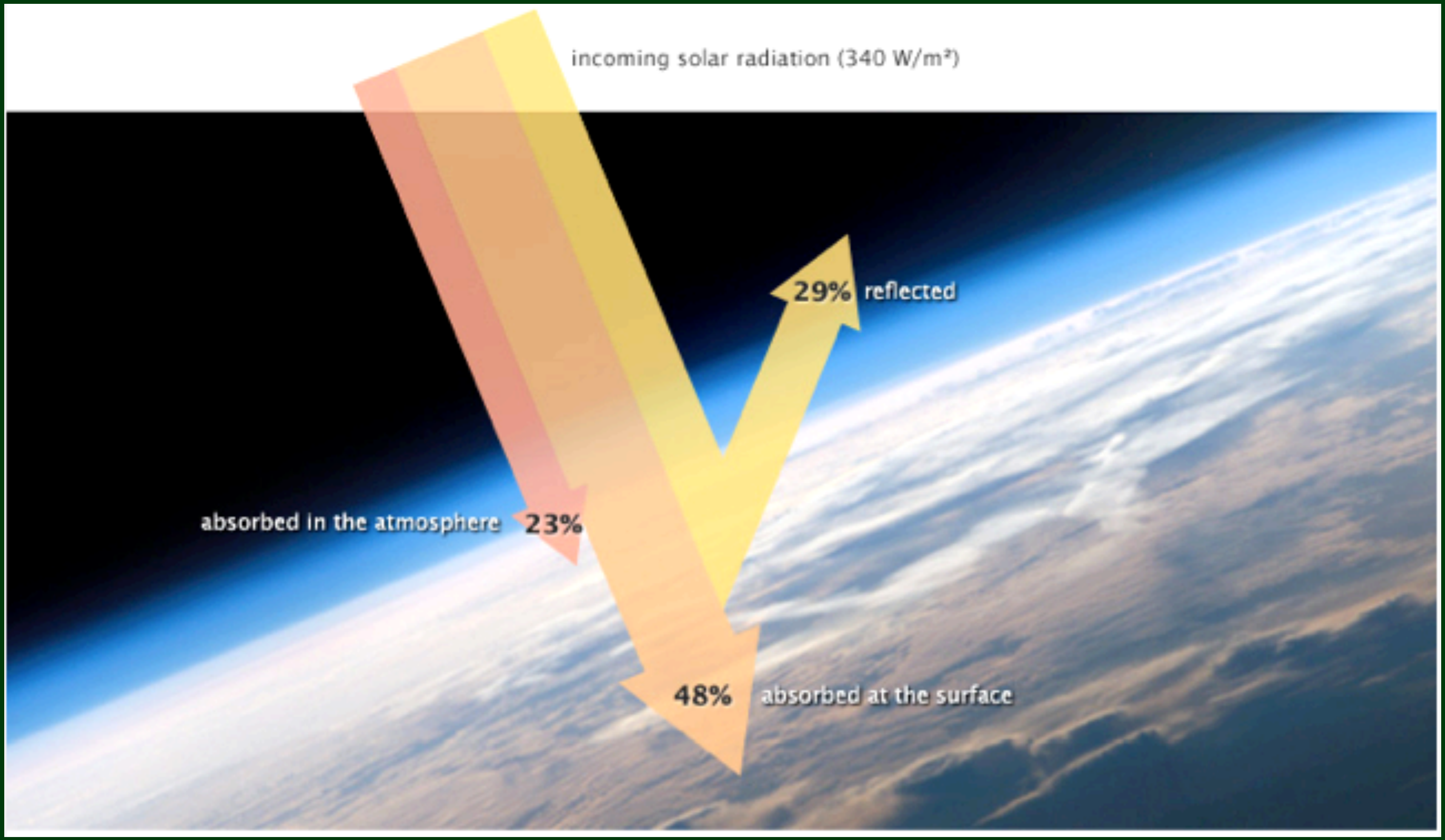
Landsat instruments measure primarily light that's *reflected* from Earth's surface.

To understand more about how Landsat sensors work, it helps to remember that –

As sunlight strikes Earth's surface, some of it is absorbed, and some of it is reflected back into space.

Image Science & Analysis Laboratory, NASA Johnson Space Center - ISS007E10807

About 25 percent of the Sun's energy is *absorbed by the atmosphere*; about 50 percent is *absorbed by the Earth's surface*; and about 30 percent is *reflected back to space*.



NASA illustration by Robert Simmon. Astronaut photograph ISS013-E-8948

Sunlight has visible light *and* infrared light, as well light of other wavelengths.

Sunlight interacts with the objects it hits. Some of it is ***absorbed*** and some of it is ***reflected*** by those objects.

Photo: Jeannette Allen

We see the light that’s reflected from objects.

Photo: Jeannette Allen

Consider a tree and its leaves.

Red, green, blue, and infrared light from the sun hit the tree and its leaves.

Infrared and green light are reflected from the tree.
Red and blue light are absorbed by the tree.

In this picture,
IR is Infrared light
R is red light
G is green light
B is blue light

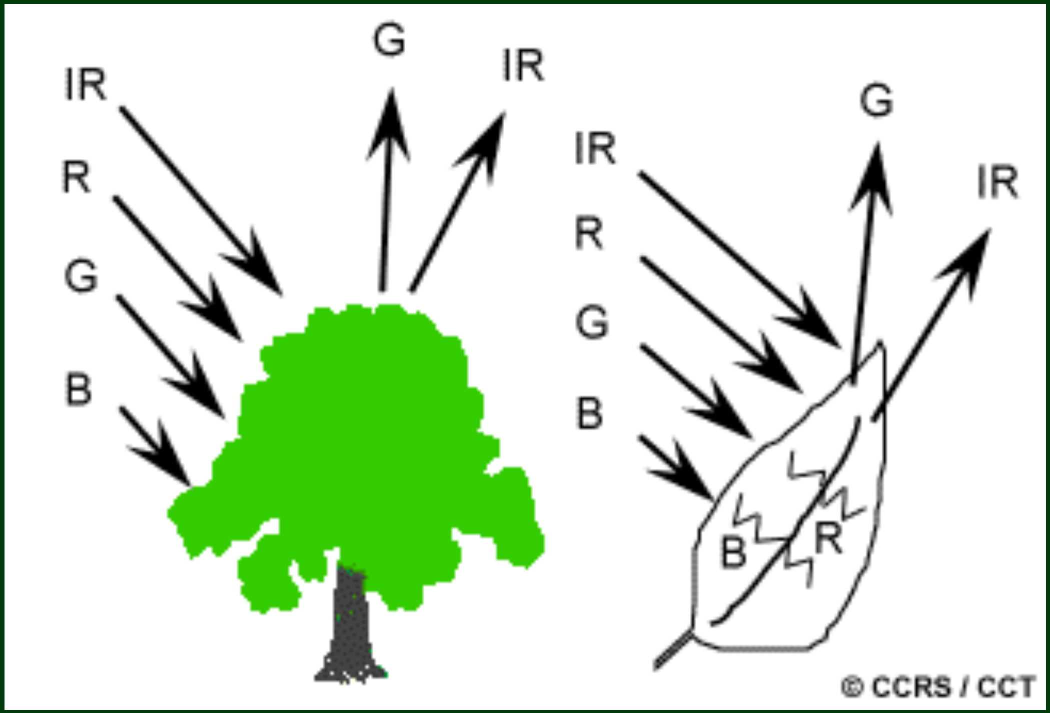


Image Credit: Canada Centre for Remote Sensing

We see the tree as green,
because wavelengths of light we call green
are reflected to our eyes by the tree.

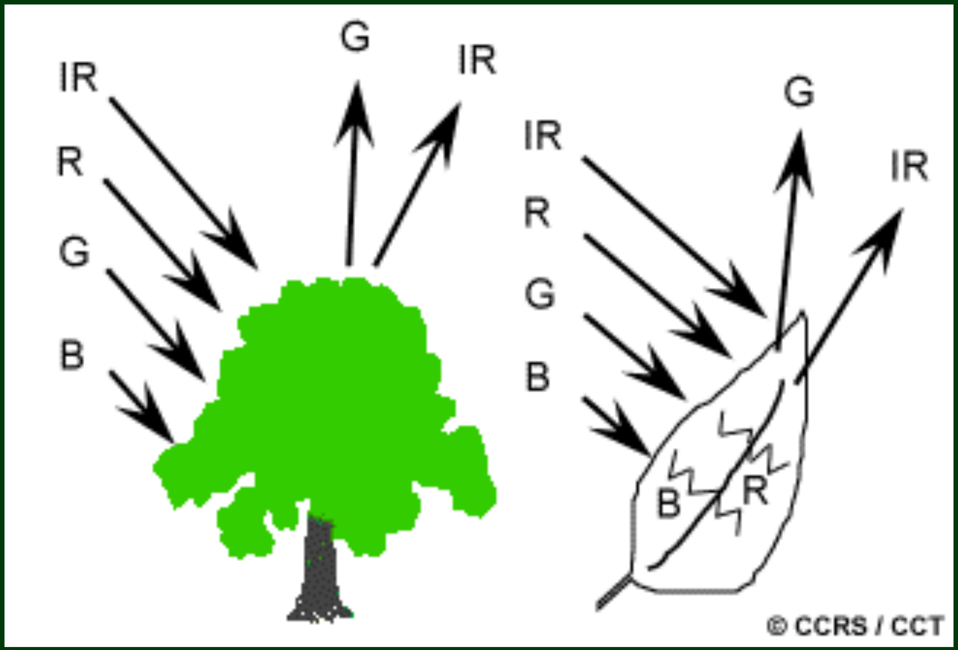
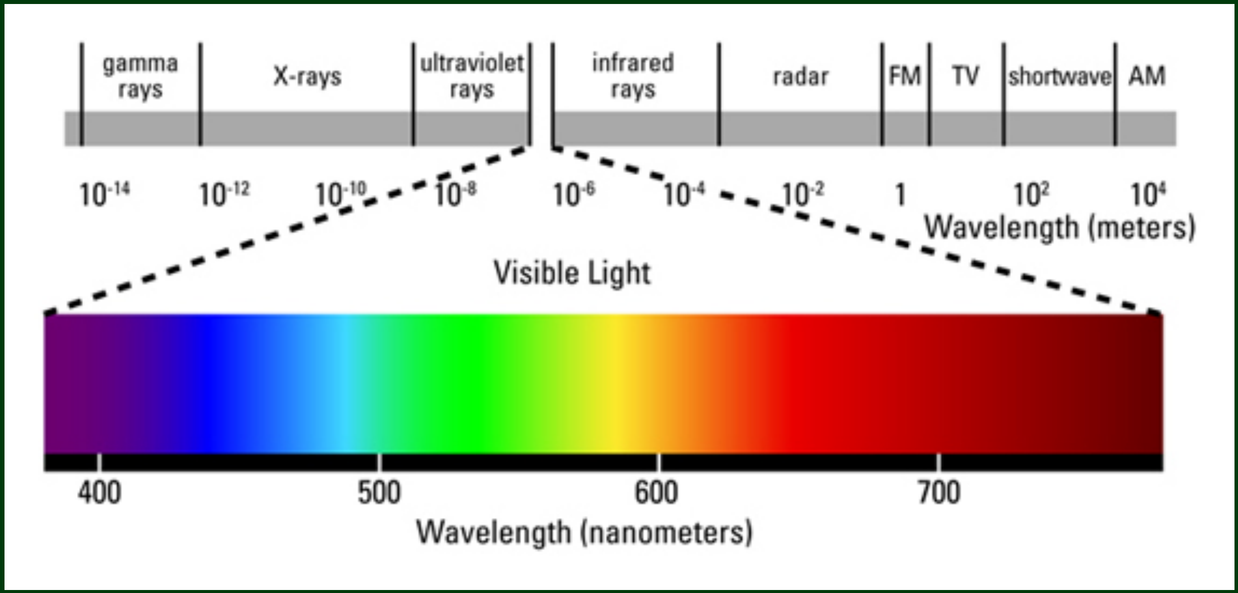


Image Credit: Canada Centre for Remote Sensing

Wavelengths we see as green are about 525-550 nanometers (nm) in length. Wavelengths we see as red are 630-800 nm in length.



The red petals of this poppy flower reflect strongly at wave-lengths of 700 nm.

Photo: Jeannette Allen

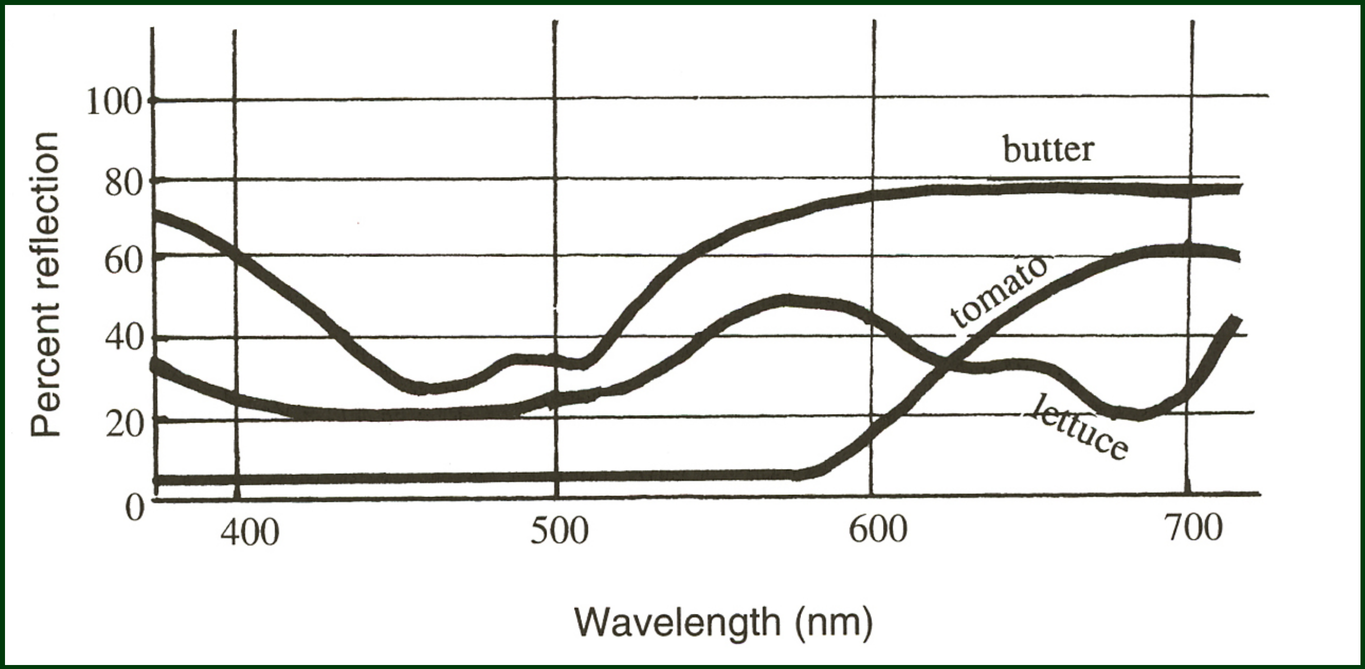
Every kind of surface reflects light differently, absorbing and reflecting it weakly or strongly in different wavelengths.

Photos: Jeannette Allen

Every kind of surface has its own *spectral signature,* somewhat like a fingerprint.

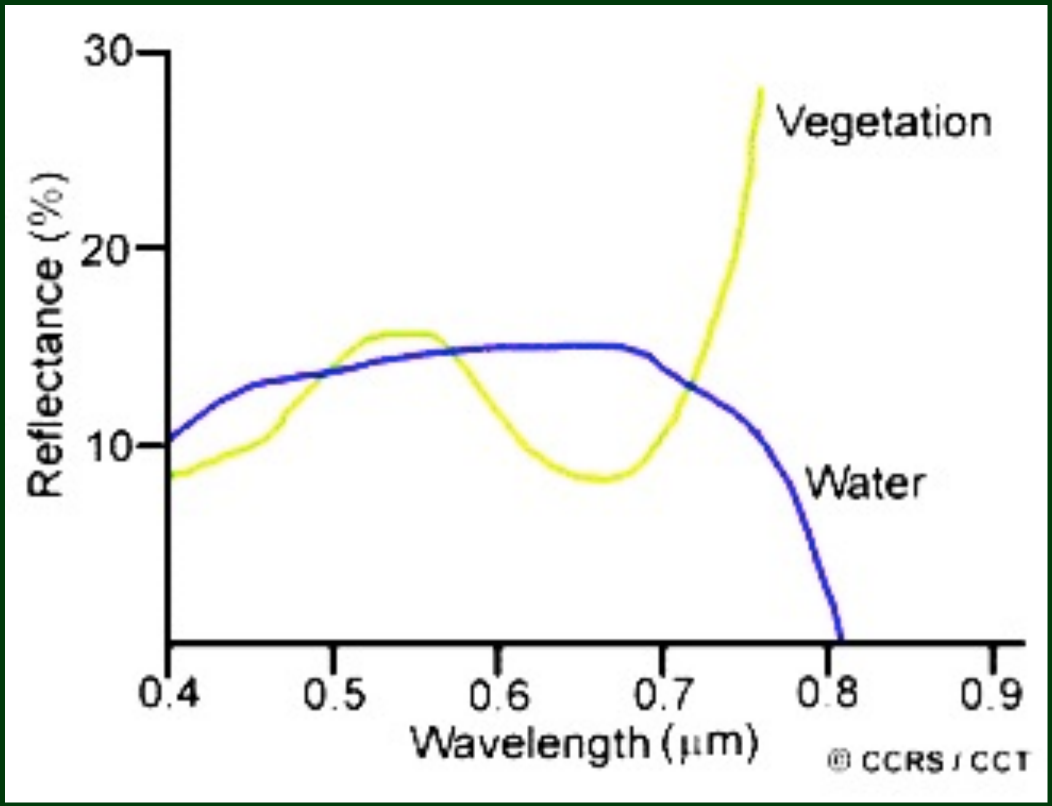
Butter reflects weakly in blue and strongly in yellow to red.
Tomato reflects weakly in blue and strongly in red.

blue yellow red



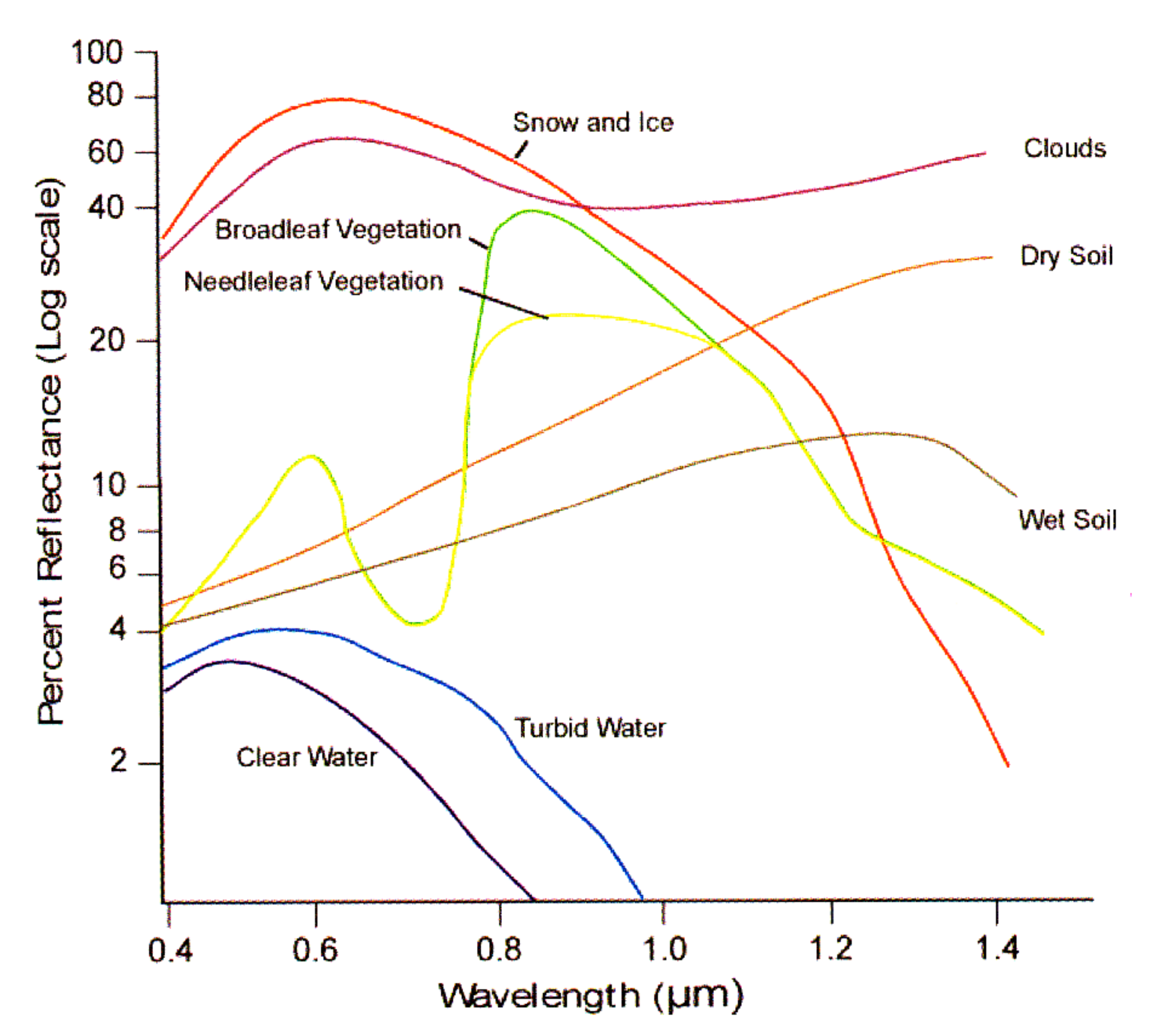
This graph shows the spectral signatures of vegetation and water.

Notice that water and vegetation reflect somewhat similarly in the visible wavelengths (about 0.4 to 0.7 nm) but are almost always separable in the infrared.



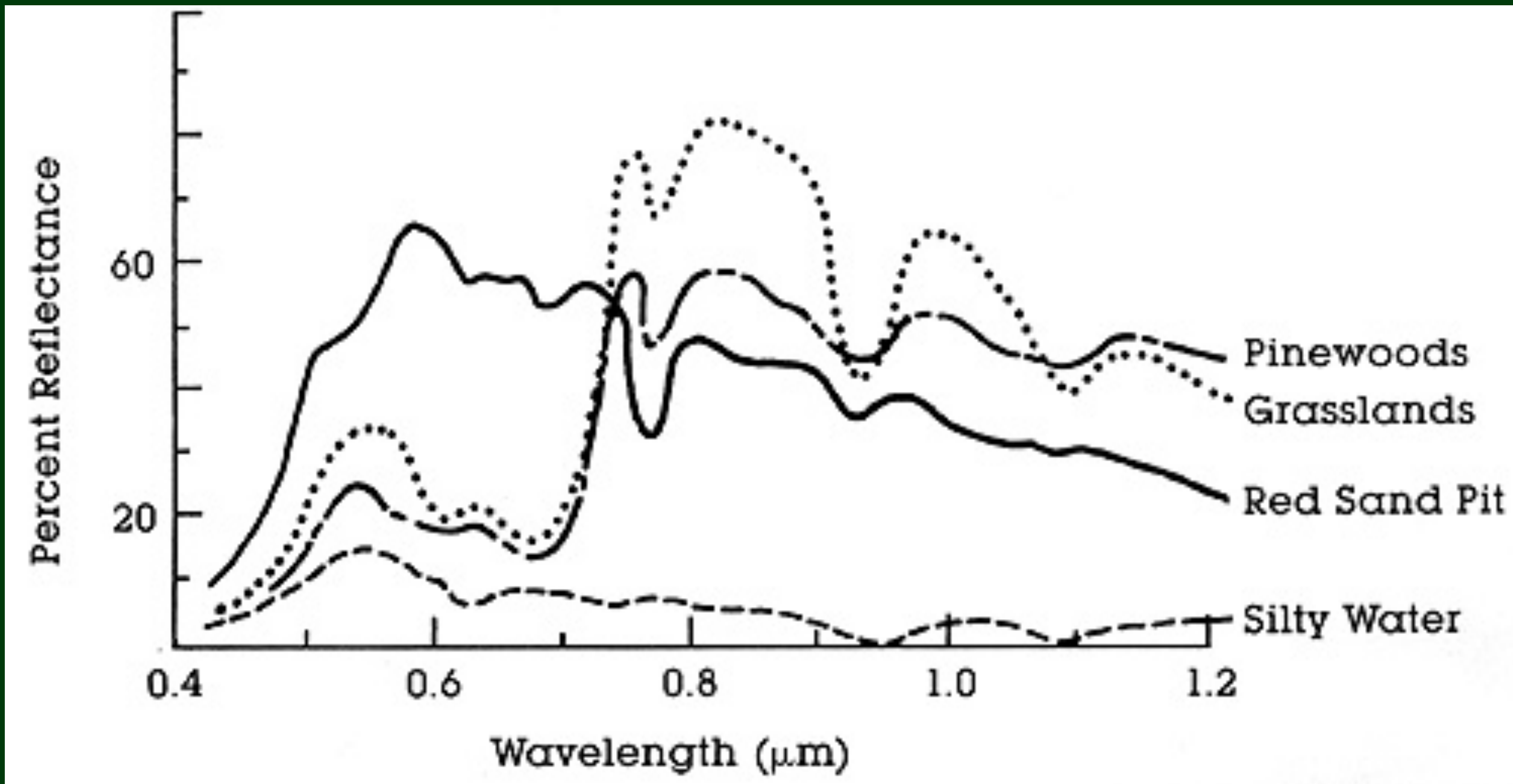
More spectral signatures.

Notice how different kinds of surfaces reflect strongly or weakly at different wavelengths.

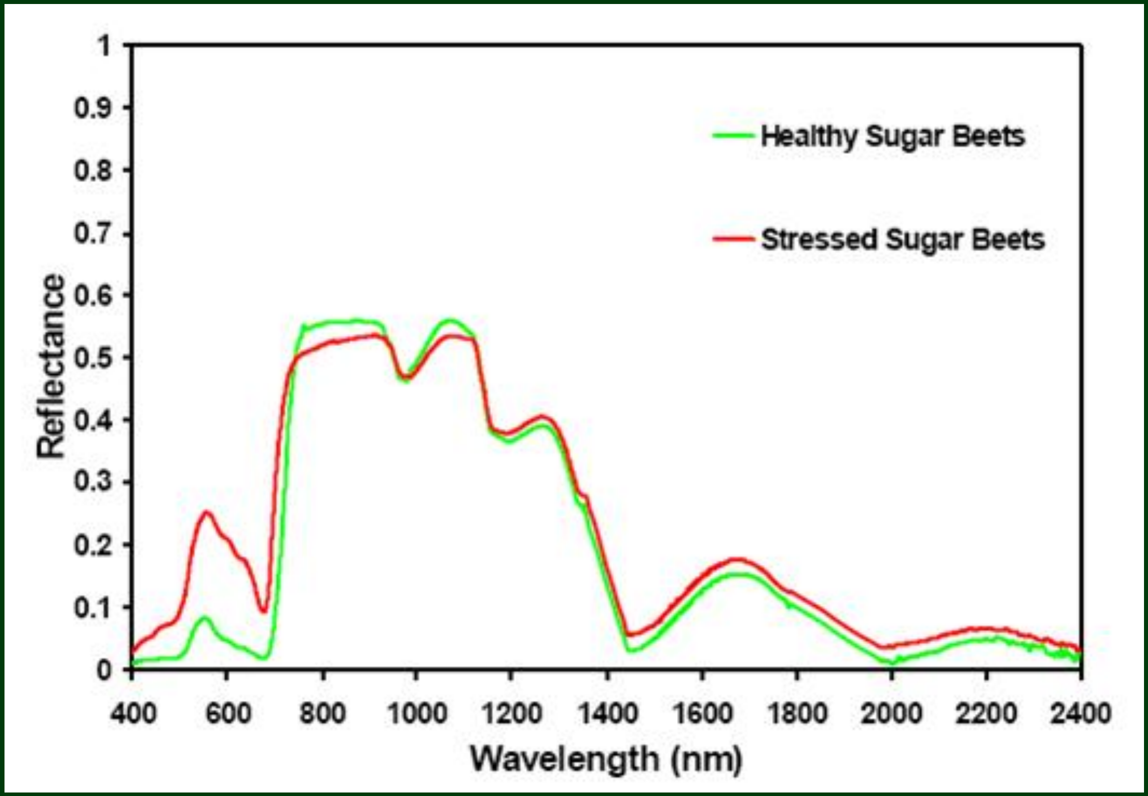


(This graph uses micrometers rather than nanometers.)

More spectral signatures



A farmer using remote sensing can tell which sugar beet fields are healthy and which are not, if she/he knows their spectral signatures.



If s/he were designing a sensor solely to measure the health of his sugar beets, what wavelength range would he want the sensor to detect?

People measure the spectral signatures of different surfaces on the ground. Then when they look at the spectral signature of a surface in a satellite image, they can tell what kind of surface the satellite was looking at.

Researcher with hand-held spectrometer

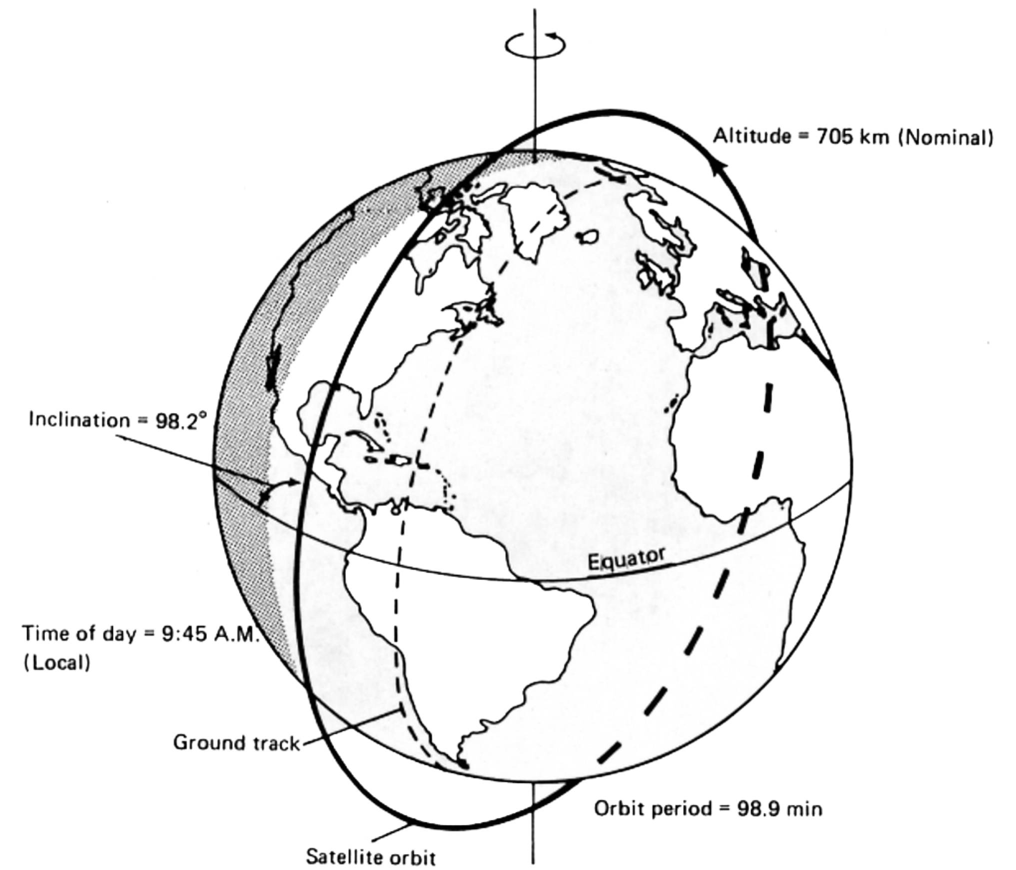
We use our understanding of spectral signatures when we study a Landsat scene.

Dragon Lake, Siberia

What's Special About Landsat

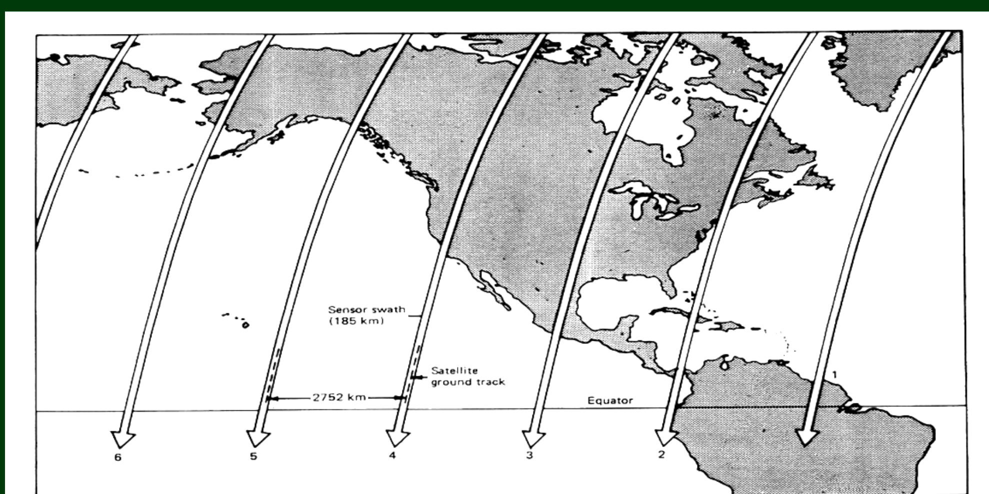
- Primary mission: to map Earth's land surface
- Data consistent since 1972
- 16 day repeat
- 30-meter resolution
- Data publicly available at no cost, thanks to USGS.

Landsat satellites orbit the Earth at 705 km above the surface.



Sun-synchronous orbit of Landsat-4 and -5. (Adapted from NASA diagram.)

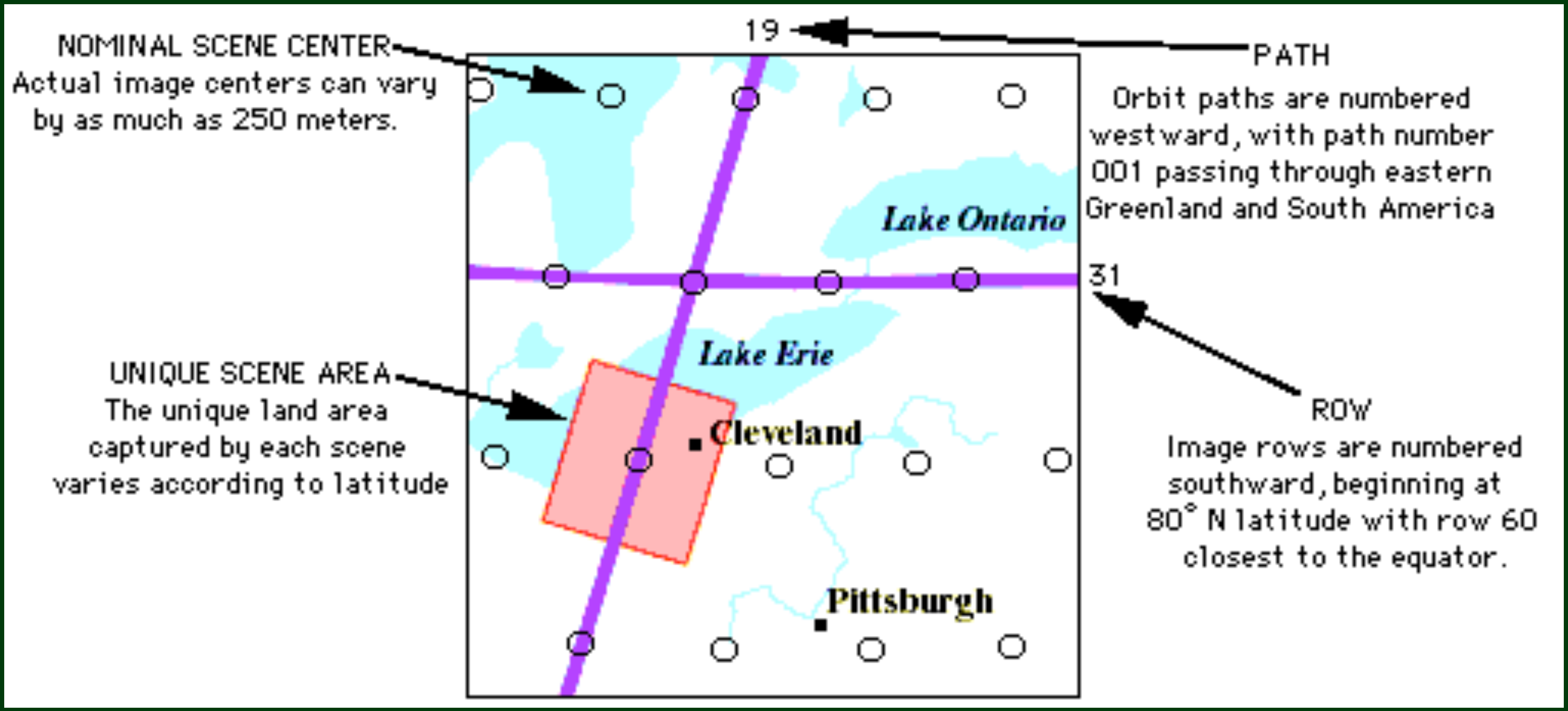
Landsat orbits from pole to pole (north, south north south), as Earth turns under it.



Spacing between adjacent Landsat-4 or -5 orbit tracks at the equator. The earth revolves 2752 km to the east at the equator between passes. (Adapted from NASA diagram.)

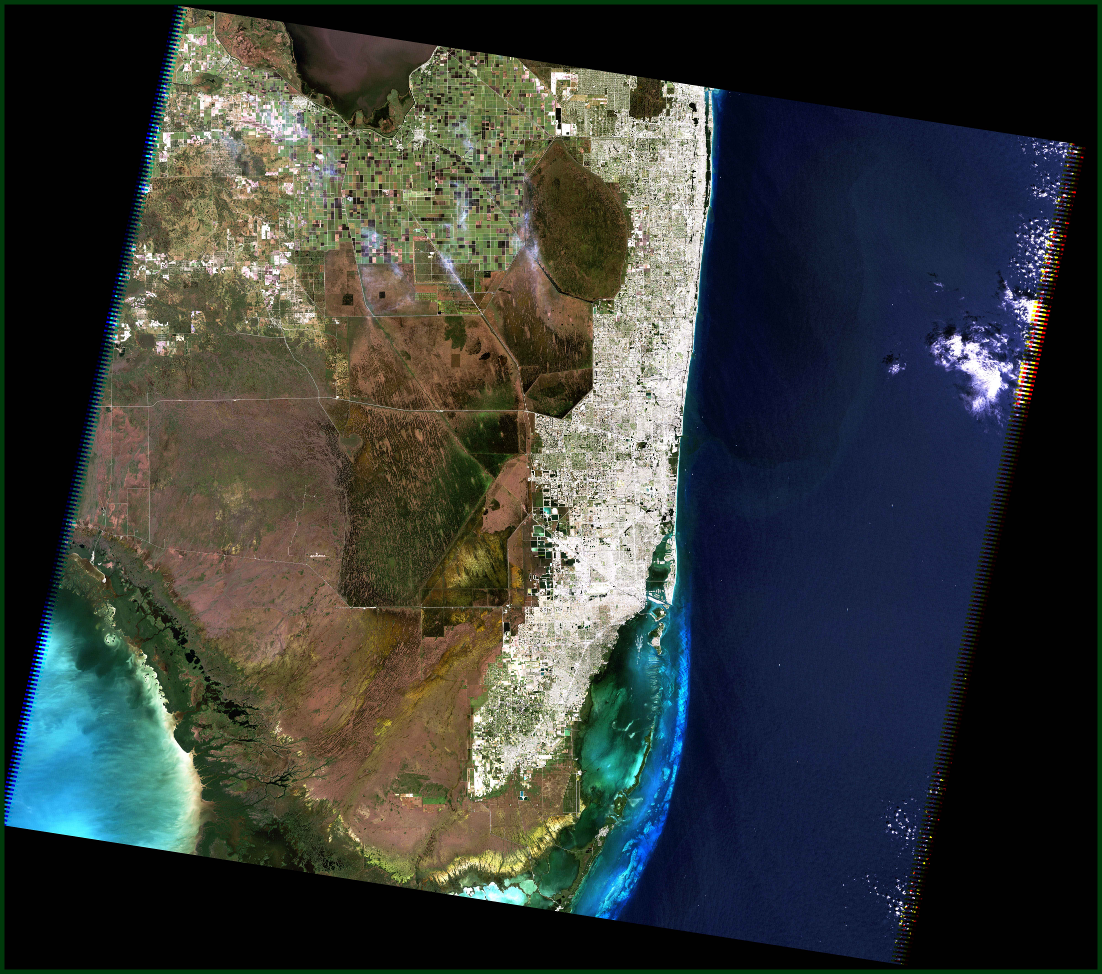
Landsat's observations are organized by those orbit paths and also by row.

… into a World Reference System associated with latitude and longitude.

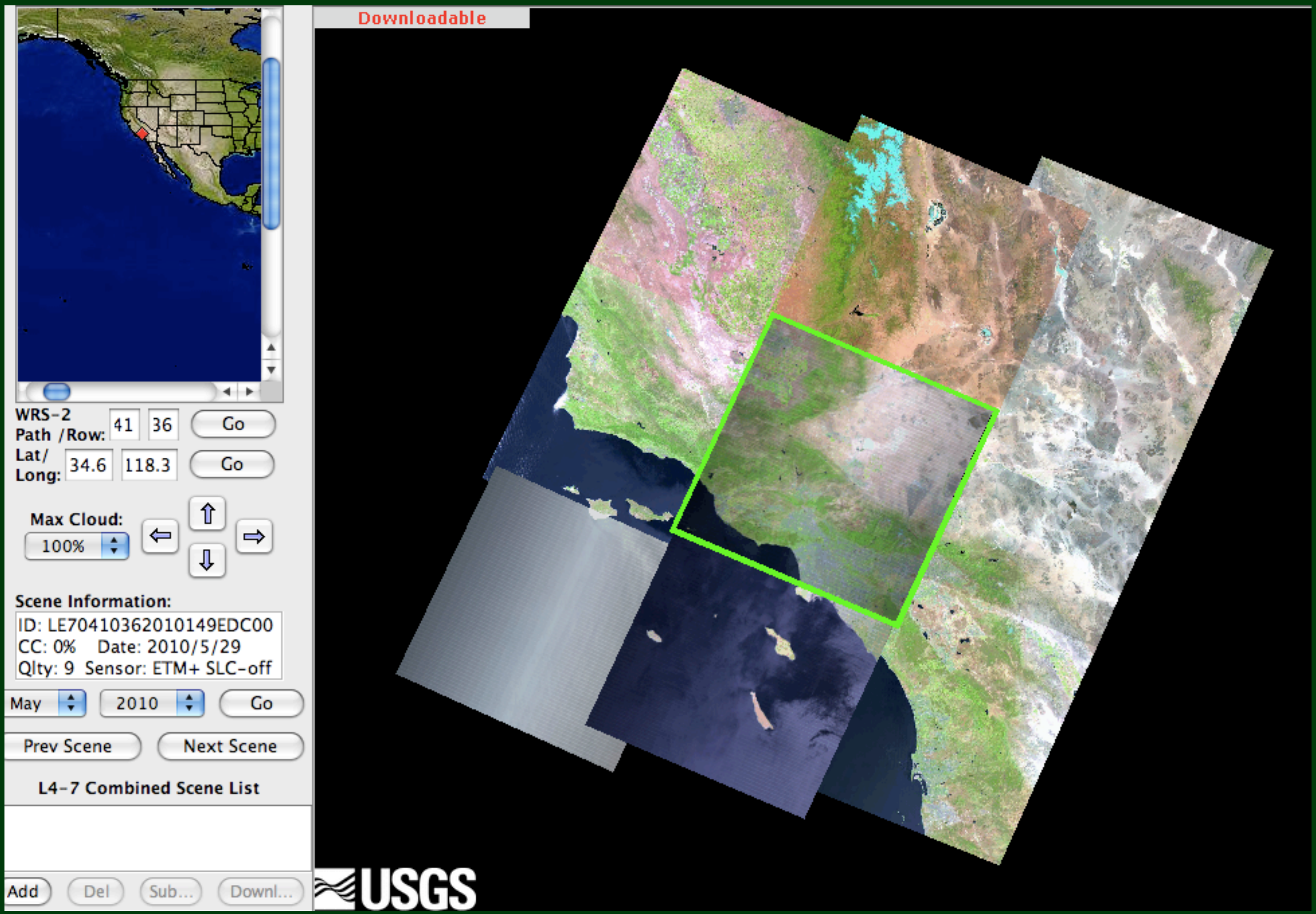


Each location on Earth's lands can be identified by its Landsat path and row, which does not change.

The Landsat scene including Miami, FL is Path 15, Row 42

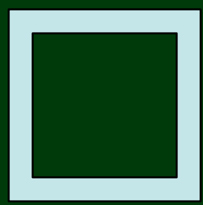


When you go to a USGS website to download a Landsat scene, you can use the scene's path and row numbers (pr its latitude and longitude).

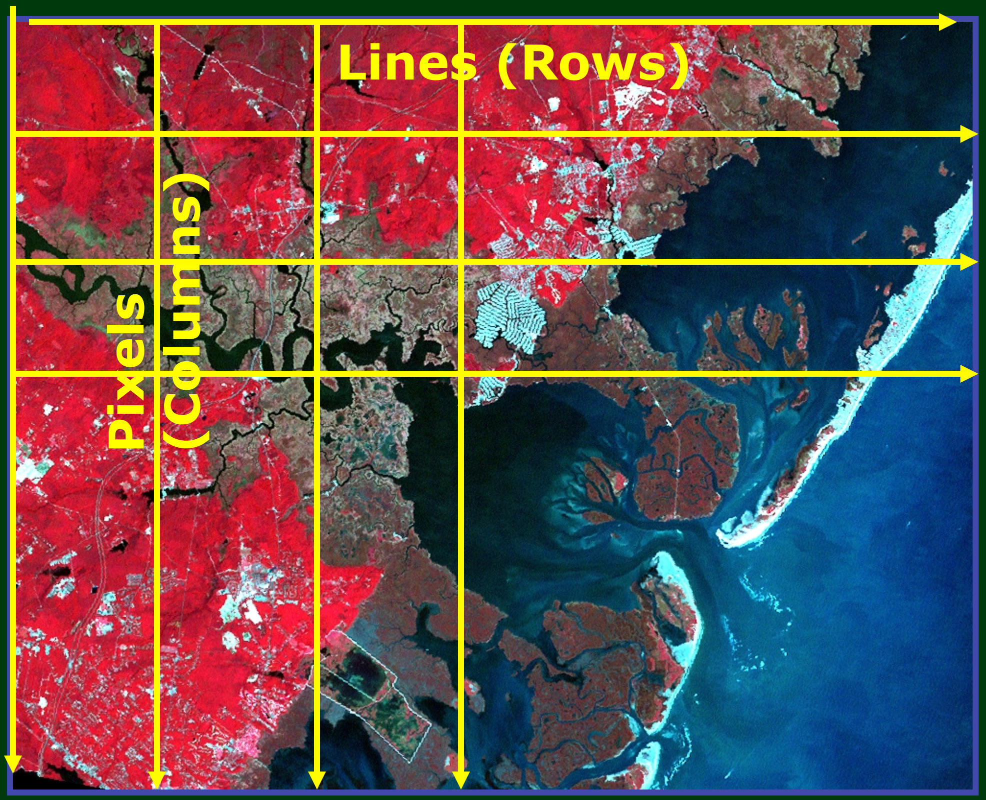


Landsat has a spatial resolution of 30 meters.

This means the smallest area on the ground
it measures is a 30 m square.



Landsat scenes are made up of these 30-meter squares, or pixels.



The pathway of light used by Landsat:

from Sun to ground, then reflected to Landsat, then transmitted to relay stations and sent to computers for analysis.

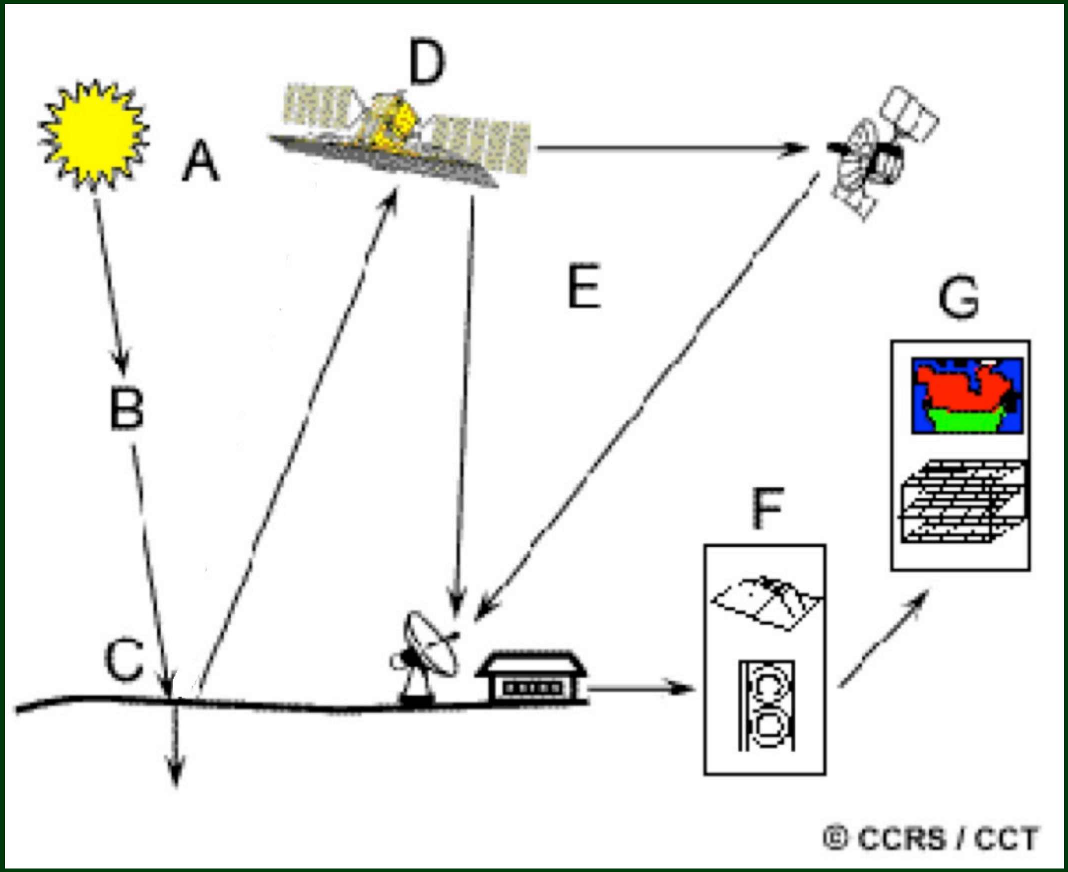
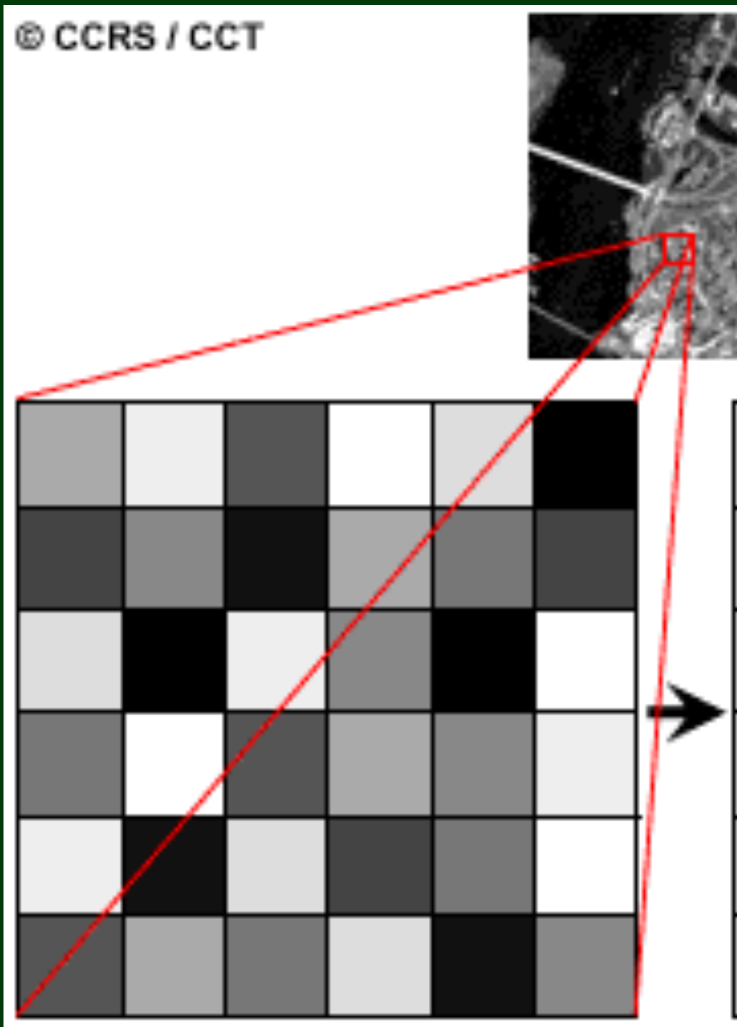


Image Credit: Canada Centre for Remote Sensing

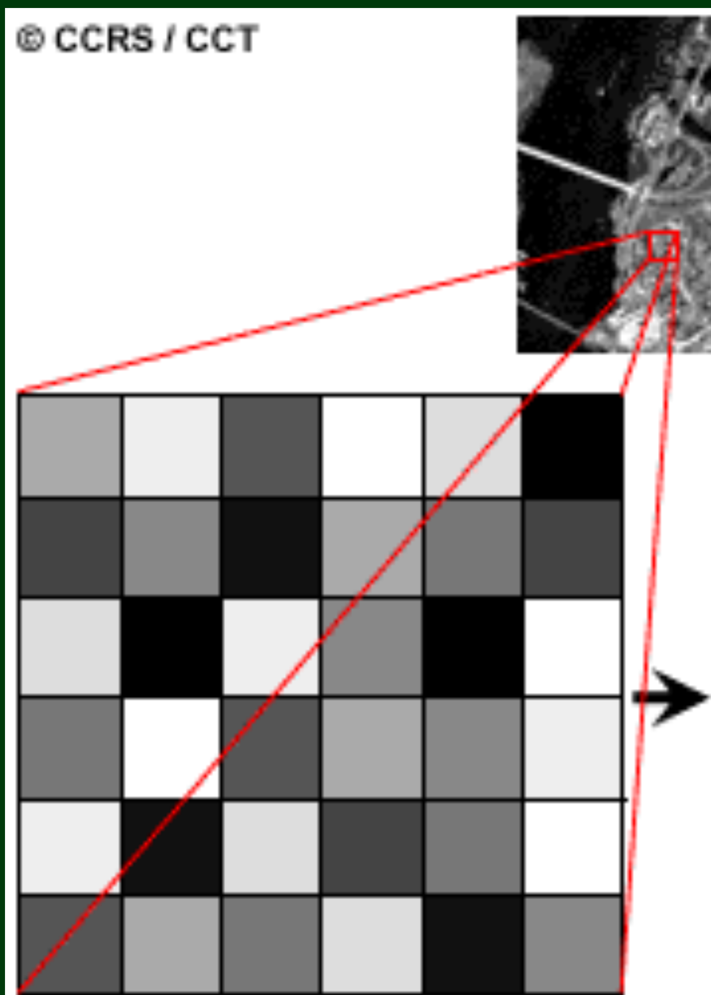
Landsat 7 observes the Earth in 7 ranges (or bands) of the electromagnetic spectrum.

Let’s look at how it works for just 1 band of the 7. In this illustration, each square represents a 30m x 30m piece of land surface.



170	238	85	255	221	0
68	136	17	170	119	68
221	0	238	136	0	255
119	255	85	170	136	238
238	17	221	68	119	255
85	170	119	221	17	136

The Landsat instrument records the amount of reflected light in each band for each 30 m pixel, on a scale of 0 to 255. A numerical value of 0 represents no reflected light and a numerical value of 255 represents maximum reflected light.

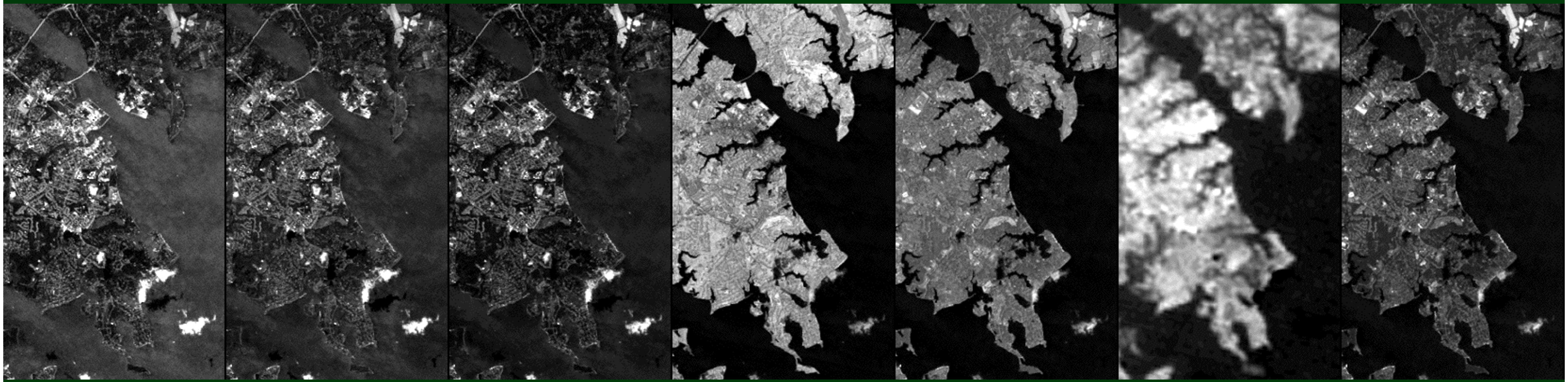


170	238	85	255	221	0
68	136	17	170	119	68
221	0	238	136	0	255
119	255	85	170	136	238
238	17	221	68	119	255
85	170	119	221	17	136

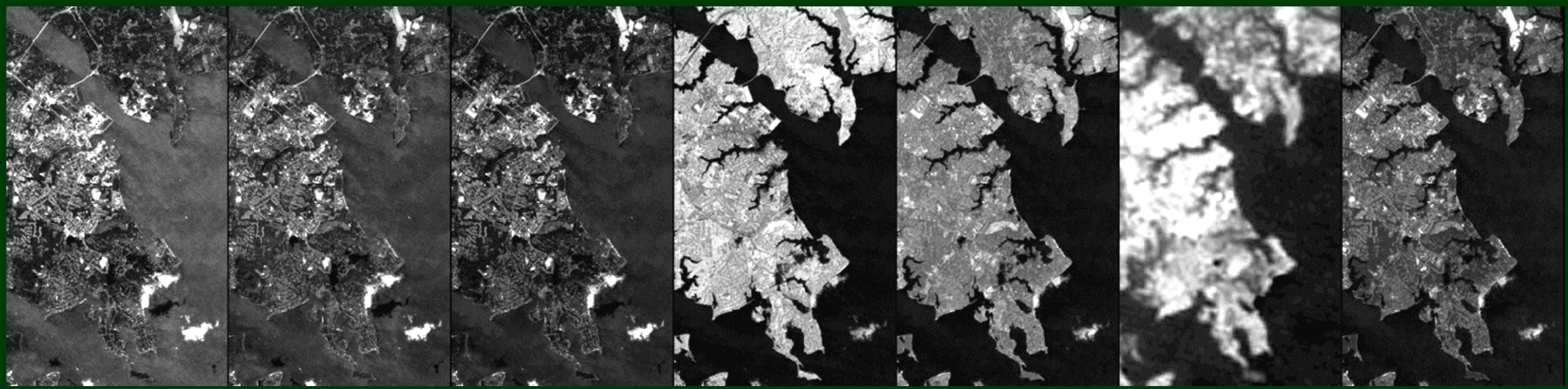
← **0**: See the corresponding black pixel in gray-scale array.

← **255**: See the corresponding white pixel in gray-scale array.

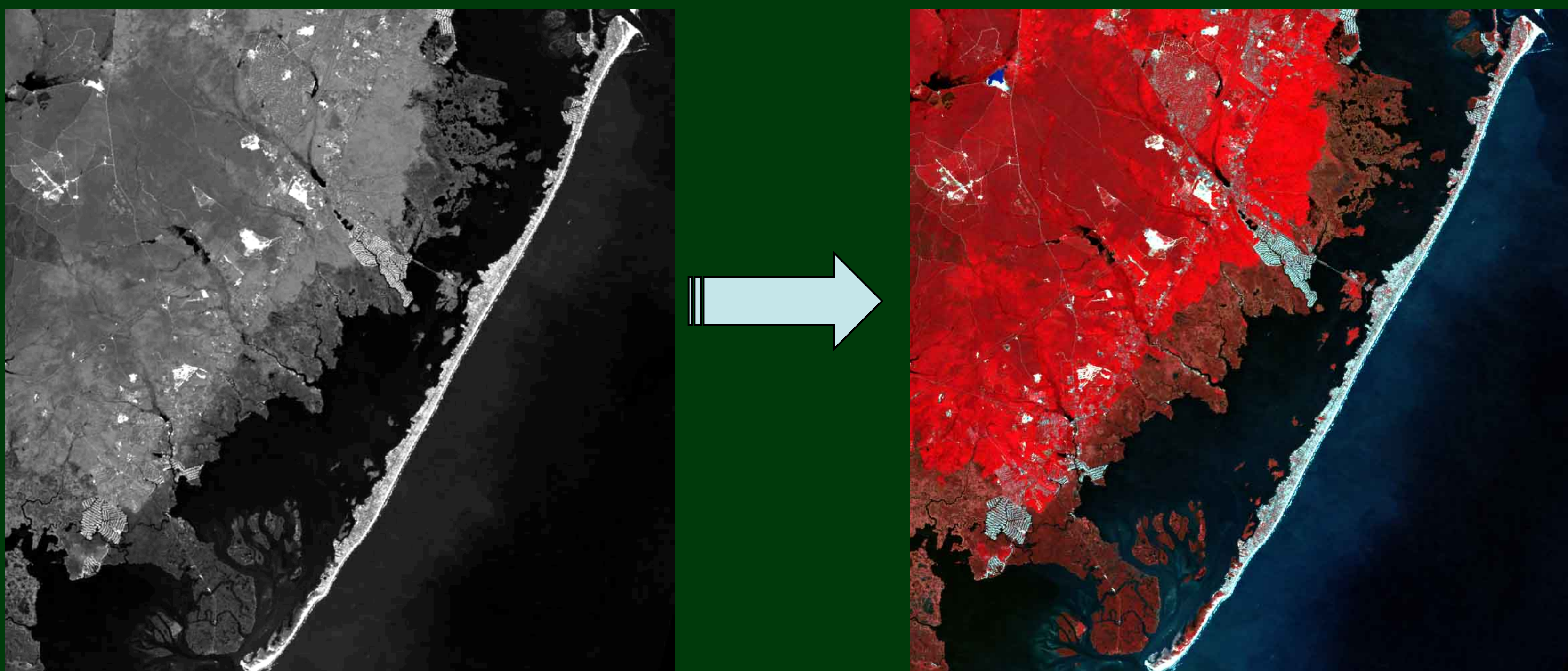
7 bands of data looked at side by side in shades of gray



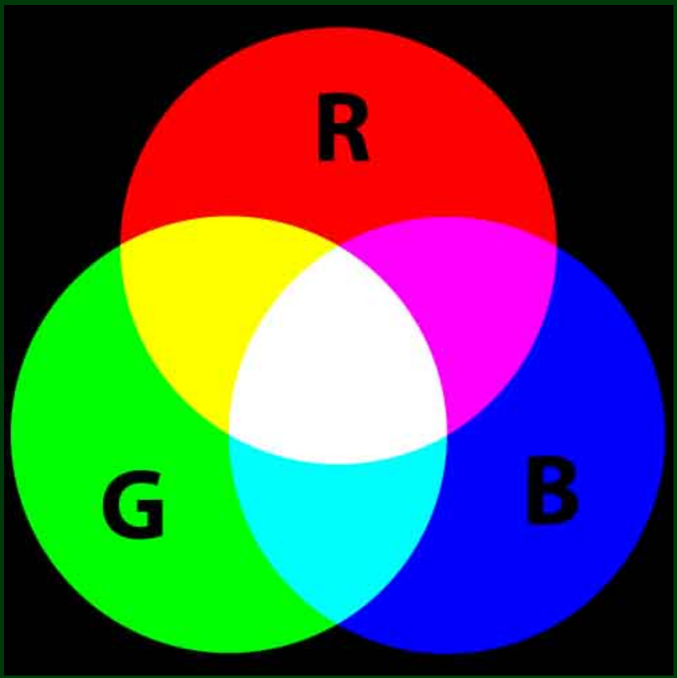
Now – how do we make color images of all that grayscale data so we can work with it more easily?



We have to *assign* **Colors** to represent Landsat bands
(using computer software).



Remember, Landsat uses some bands of ***infrared light.*** And the human eye is ***not sensitive*** to infrared. So to build an image we can see that includes data about infrared light gathered by Landsat, we must represent that data with colors we can see: red, green, and blue.



Here's an example.

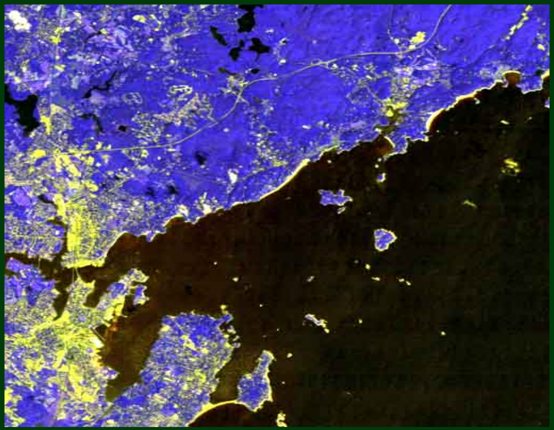
In the images of New Jersey Barrier Islands below, data about reflected near-infrared light (Landsat's Band 4) has been assigned the color red in the image at lower right.

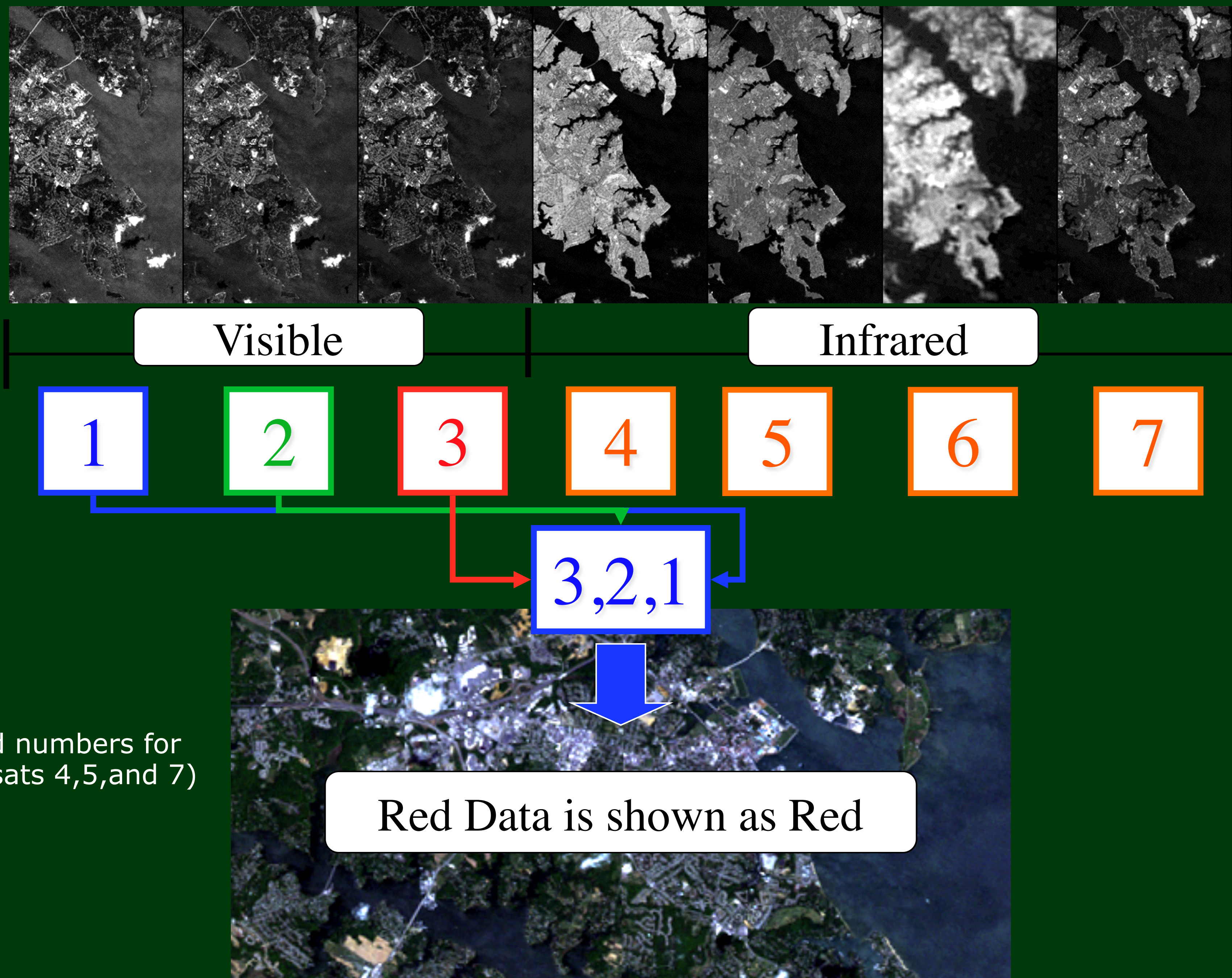
Reflected near-infrared light appears in shades of gray.

Reflected near-infrared light appears in shades of red.

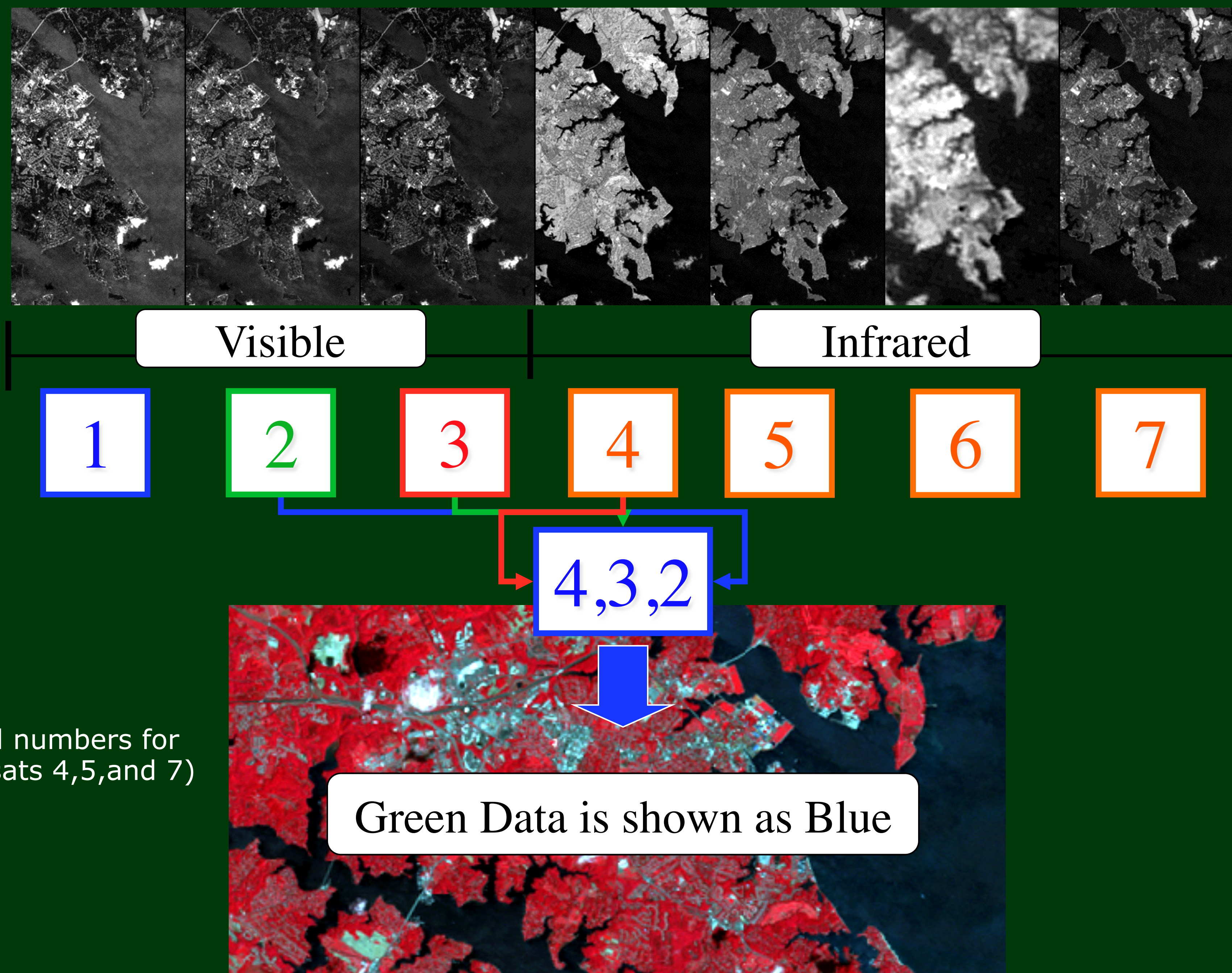
People can chose red, green, or blue to represent any of the wavelength ranges they like.

One can make lots of color combinations. (This is Beverly, MA.)





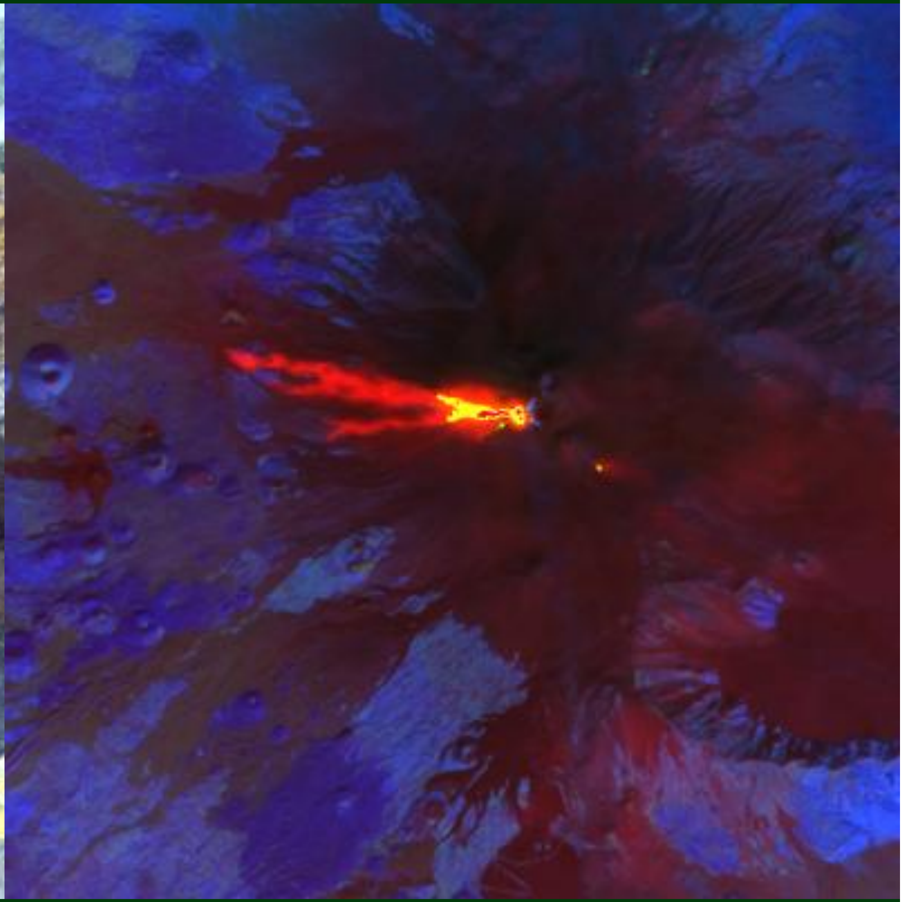
(Band numbers for Landsats 4,5,and 7)



(Band numbers for Landsats 4,5,and 7)

Making images with different band combinations, we see more than we could otherwise.

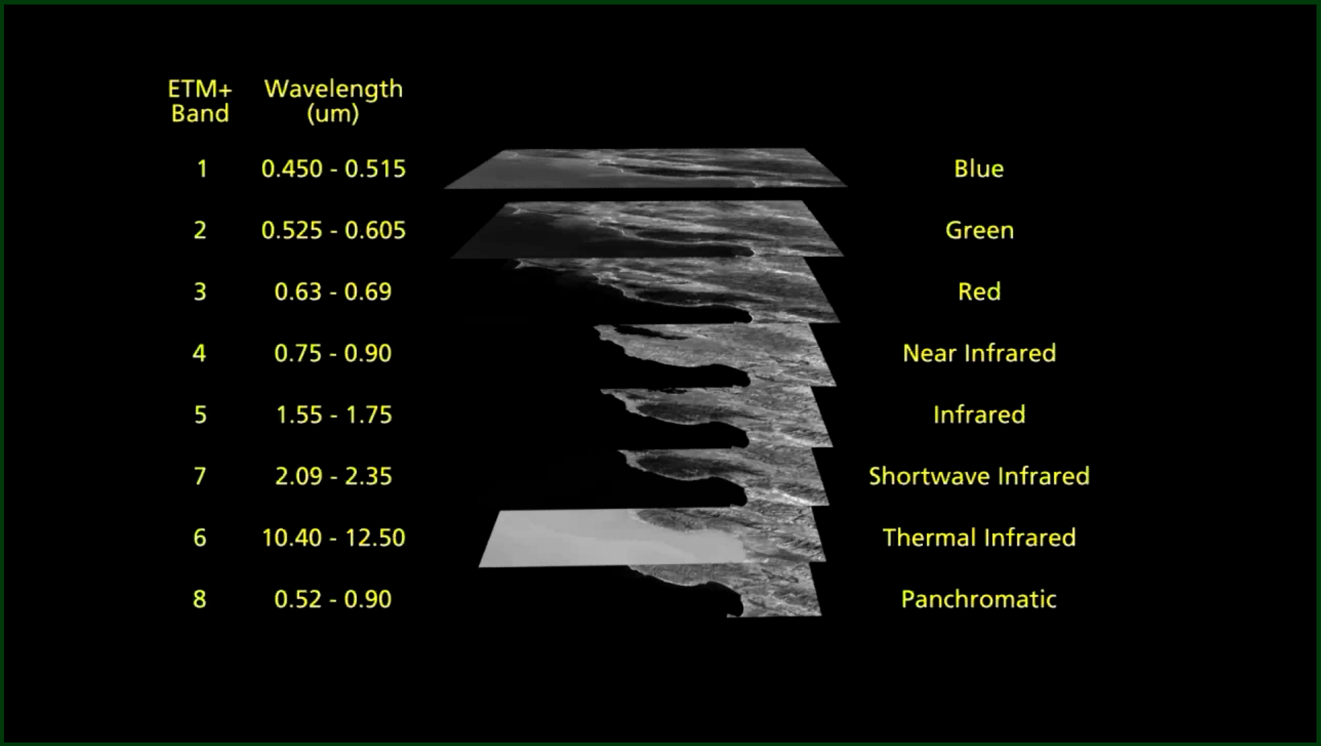
Same scene, different wavelengths



Visible wavelengths

Infrared wavelengths

To view a short movie about how wavelength ranges (bands) are combined to make an image, go to:
https://svs.gsfc.nasa.gov/936



To view a longer movie about how spectral bands are combined to make an image, visit:

https://svs.gsfc.nasa.gov/11491

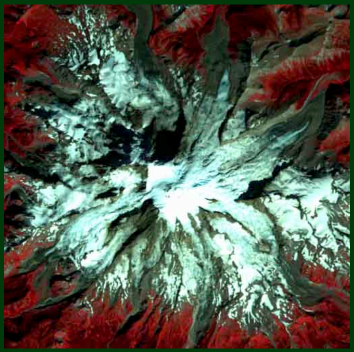
Some common band combinations…

True-Color Composite (3,2,1) L8 = 4,3,2

True-color composite images approximate the range of vision for the human eye, and hence these images appear to be close to what we would expect to see in a normal photograph. True-color images tend to be low in contrast and somewhat hazy in appearance. This is because blue light is more susceptible than other bandwidths to scattering by the atmosphere. Broad-based analysis of underwater features and landcover are representative applications for true-color composites.

Near Infrared Composite (4,3,2) L8 = 5,4,3

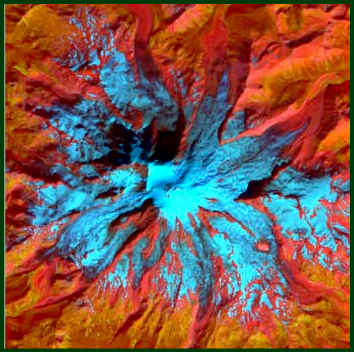
Adding a near infrared (NIR) band and dropping the visible blue band creates a near infrared composite image. Vegetation in the NIR band is highly reflective due to chlorophyll, and an NIR composite vividly shows vegetation in various shades of red. Water appears dark, almost black, due to the absorption of energy in the visible red and NIR bands.



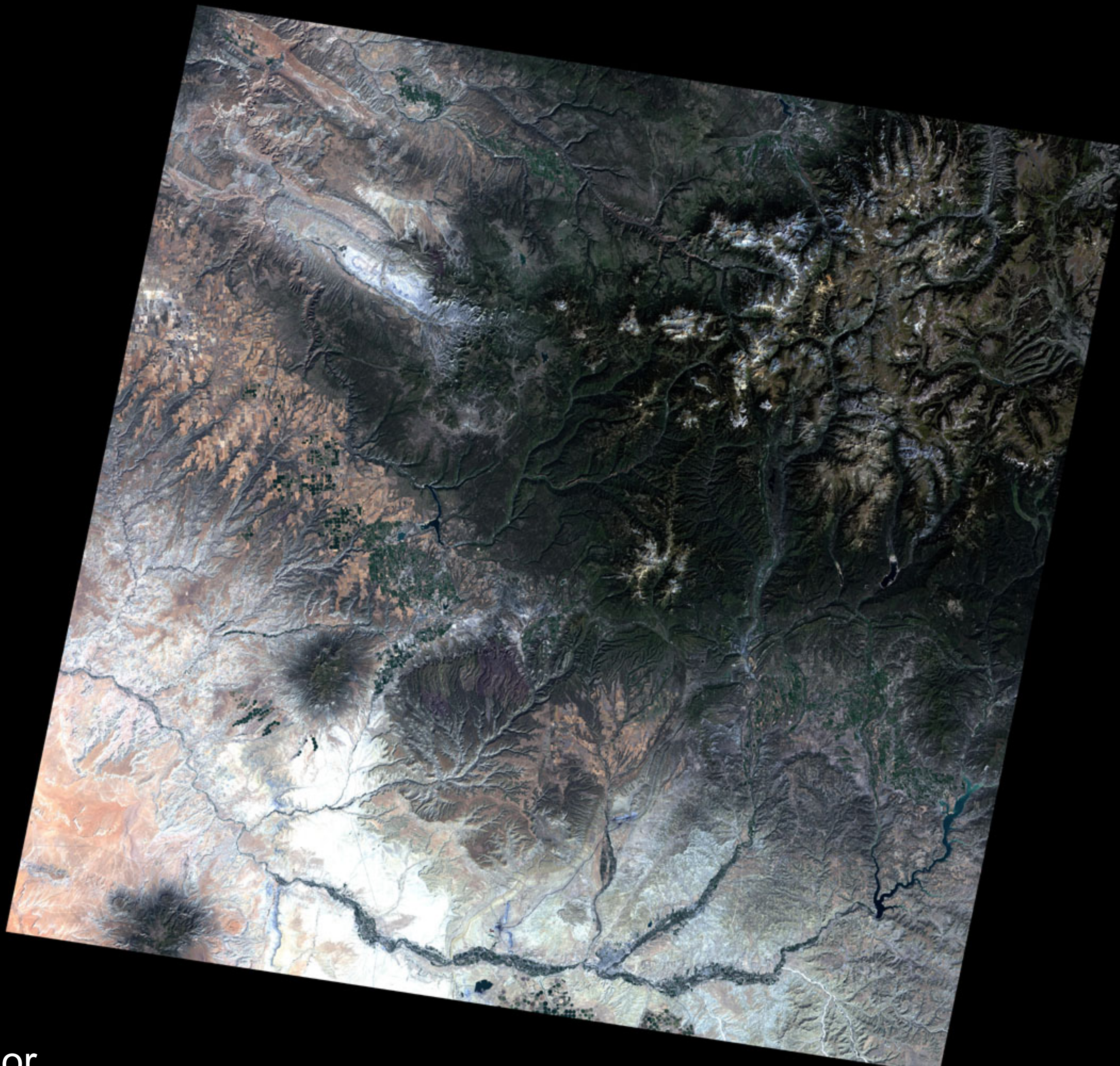
Shortwave Infrared Composite (7,4,3 or 7,4,2) L8 = 7,5,4 + 7,5,3

A shortwave infrared composite image is one that contains at least one shortwave infrared (SWIR) band. Reflectance in the SWIR region is due primarily to moisture content. SWIR bands are especially suited for camouflage detection, change detection, disturbed soils, soil type, and vegetation stress.

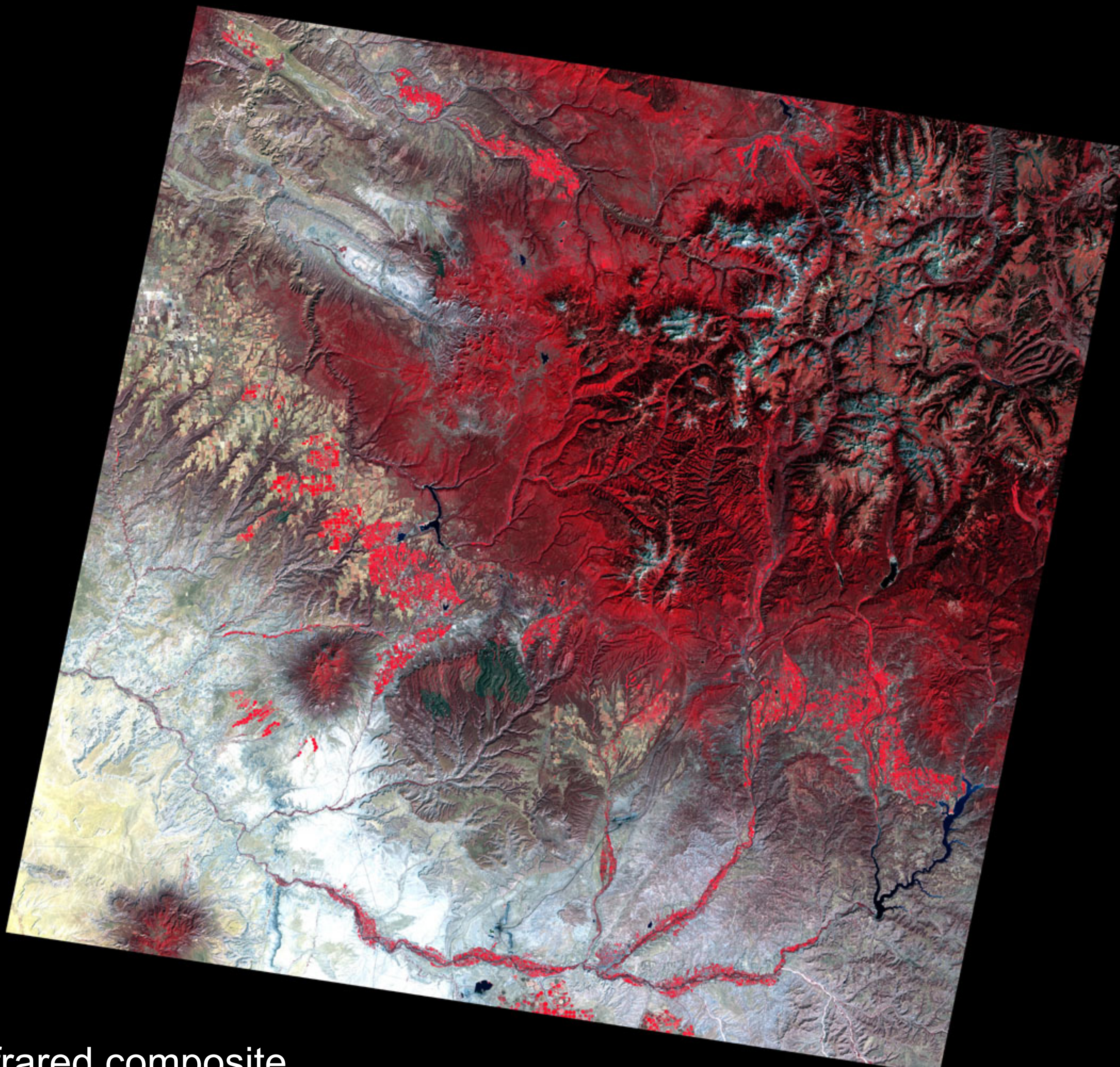
Mount Rainier



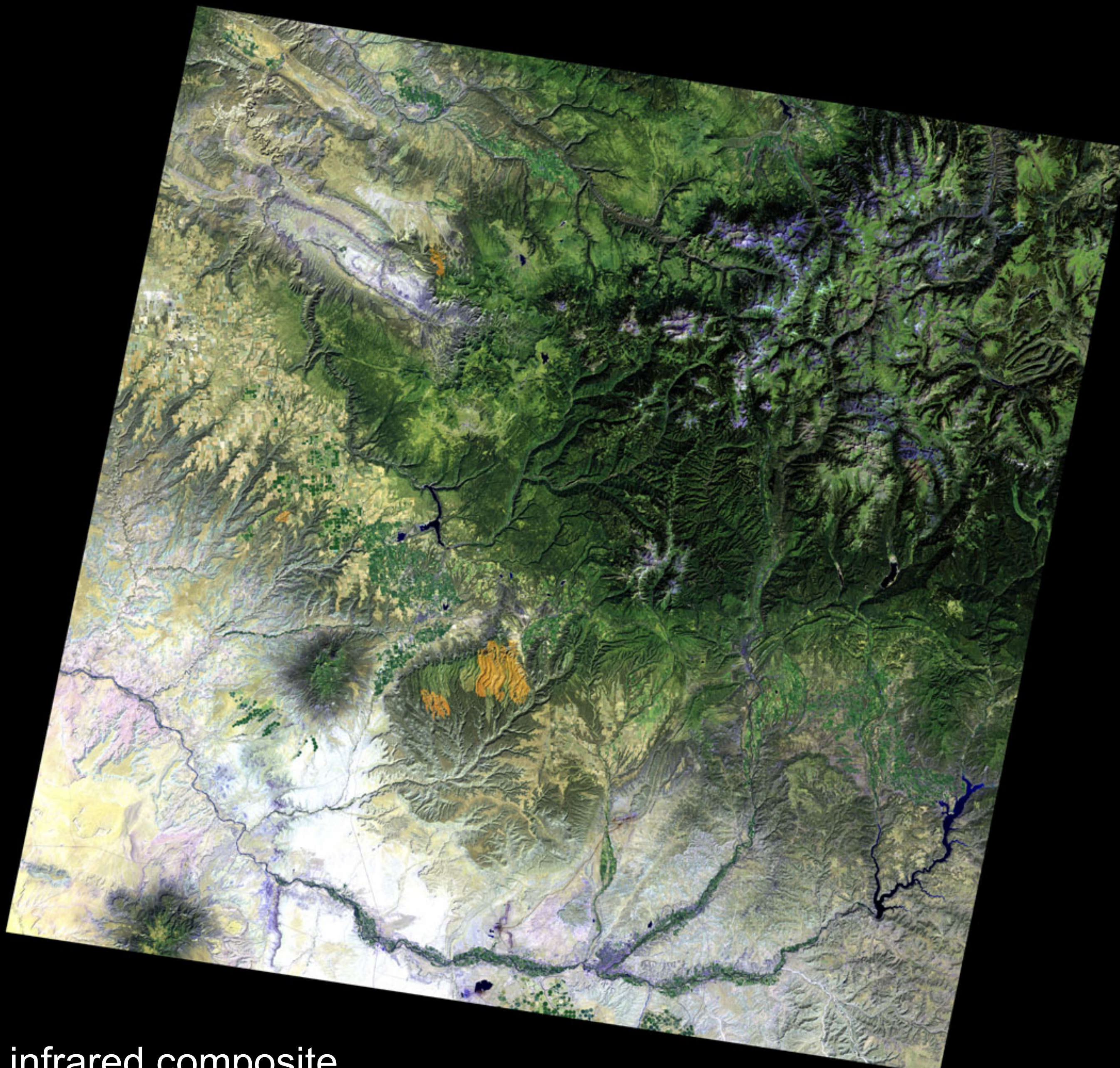
Landsat 7, Path 35 Row 34, 09.12.00



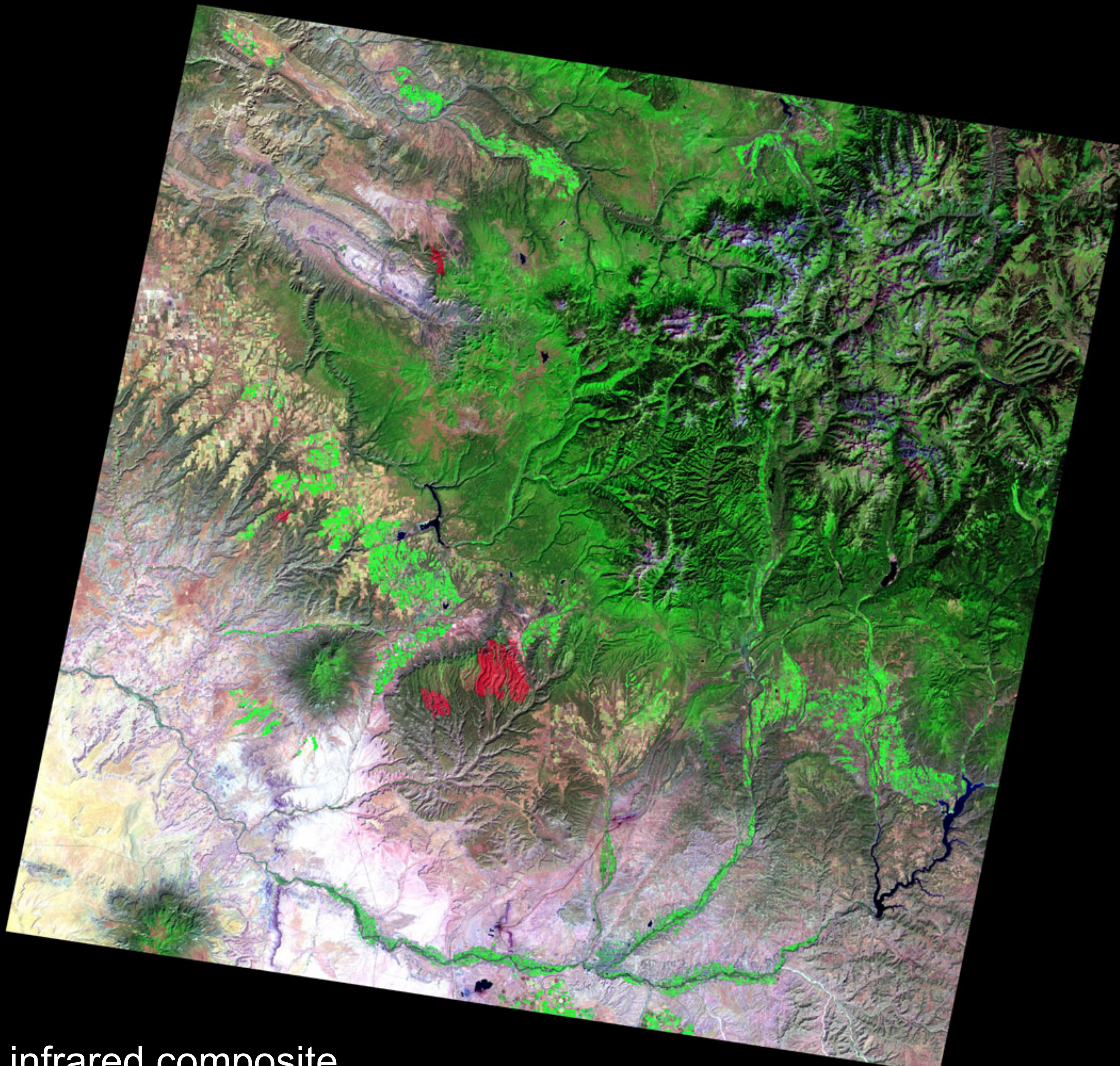
True color



Near-infrared composite



Another infrared composite



Another infrared composite

A little more to know:

The newest Landsat satellite, Landsat 8, measures the amounts of reflected light on a *finer scale* than Landsat 7's scale of 0-255.

Landsat 8 measures light on a scale of 0-4095.

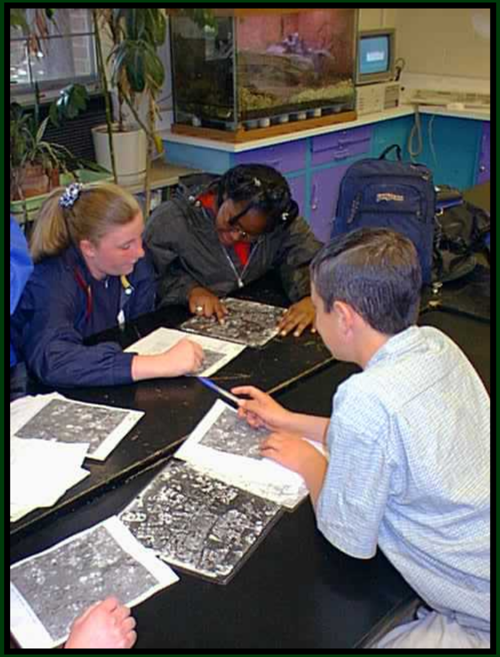
With Landsat 8 we can see many more shades of the light we are measuring, and we can study greater nuance in our scenes of interest.

Landsat 8 also uses more bands of light than Landsat 7, and the band numbers are a little different.

To learn the differences between Landsat 7 and Landsat 8 spectral bands, go to this URL:

http://landsat.usgs.gov/L8_band_combos.php

What scientists & students can do with Landsat



- Learn what's behind Google Earth, and the power of data behind the imagery
- Map, analyze, and predict urban growth and impervious surfaces
- Monitor crop health
- Monitor forest health
- Measure deforestation and reforestation
- Quantify amount of land used in surface mining
- Track mountaintop removal
- Determine the extent of flood zones for emergency response and assessment of insurance claims
- Map extent and severity of forest fires
- Monitor seasonal wetlands to help predict the spread of pest-borne diseases

With Landsat, scientists can also –

- Estimate amounts of carbon stockpiled in vegetation.
- Quantify water use on specific farms and rangelands.
- Improve forest inventories to predict tree growth and product yield.

Graduate students in forestry from the University of California, Los Angeles take a break from field work in Siberia.

Photo Credit: Kenneth J. Ranson

National Aeronautics and Space Administration
http://www.nasa.gov